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Miscellaneous Report 88-4

Summary of Investigations 1988, Saskatchewan Geological Survey

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Foreword

The Summary of Investigations 1988 marks the 29th year that the department has issued a summary report of its geoscientific activities. Rather than write the traditional "executive summary" type of foreword I thought it would be interesting to reflect on the growth and development of this annual document.

Early reports were modest in length and style and, as suggested by their title "Summary Report of Geological Investigations Conducted in the Precambrian Area of Saskatchewan", were exclusively devoted to the northern geological program of the department, primarily areal geological mapping, initially on a scale of 1:63,360 and later by regional surveys at 1:100,000.

In 1974 the term "Precambrian" was omitted to reflect the broader scope of the report, which from that year onwards has included accounts of all geoscience projects of the department, as well as those carried out by other agencies and individuals under contract or in joint venture with the department.

The following year marked another major change in the format and content of the report. The text was accompanied by preliminary blue-line maps of all field projects, almost a heretic development, as few in the geological community believed that a geological map, readable by anyone else but the author, could be available for public consumption merely two months after the end of the field season. To the best of my recollection, I believe we were the first Survey in North America to accomplish this, and have yet to be followed by a number of jurisdictions. The catalyst for this initiative was Dr. J.J. Brummer of Toronto, who quite rightly pointed out that "a preliminary geological report was of little value to industry without a map, and even a copy of the field map was better than nothing". I would suggest that the standard of preliminary maps produced in the last several years may have exceeded even Joe Brummer's expectations.

To produce a report of this size and quality in the short time available is largely due to the skill and hard work of the editors. Credit for current standards is primarily due to the sustained efforts of Bob Macdonald (Senior Editor) and Bob Davie (Production Editor). This year's report was published by desk-top publishing software and laser printer and Bob Davie is to be congratulated for the smooth transition to new production techniques. Regretfully Bob Davie is leaving Saskatchewan and we wish him well in his attempts to bring technological change to one of the other provincial surveys.

The Summary of Investigations 1988 covers most of the geoscientific work of Saskatchewan Energy and Mines and includes papers by the Geological Survey of Canada, Saskatchewan Research Council and the Universities of Saskatchewan, Regina, Ottawa, Waterloo, Kansas, California and Birmingham (U.K.), as well as by two private consultants. These contributions are gratefully acknowledged.

L.S. Beck
Executive Director
Geology and Mines Division

November, 1988

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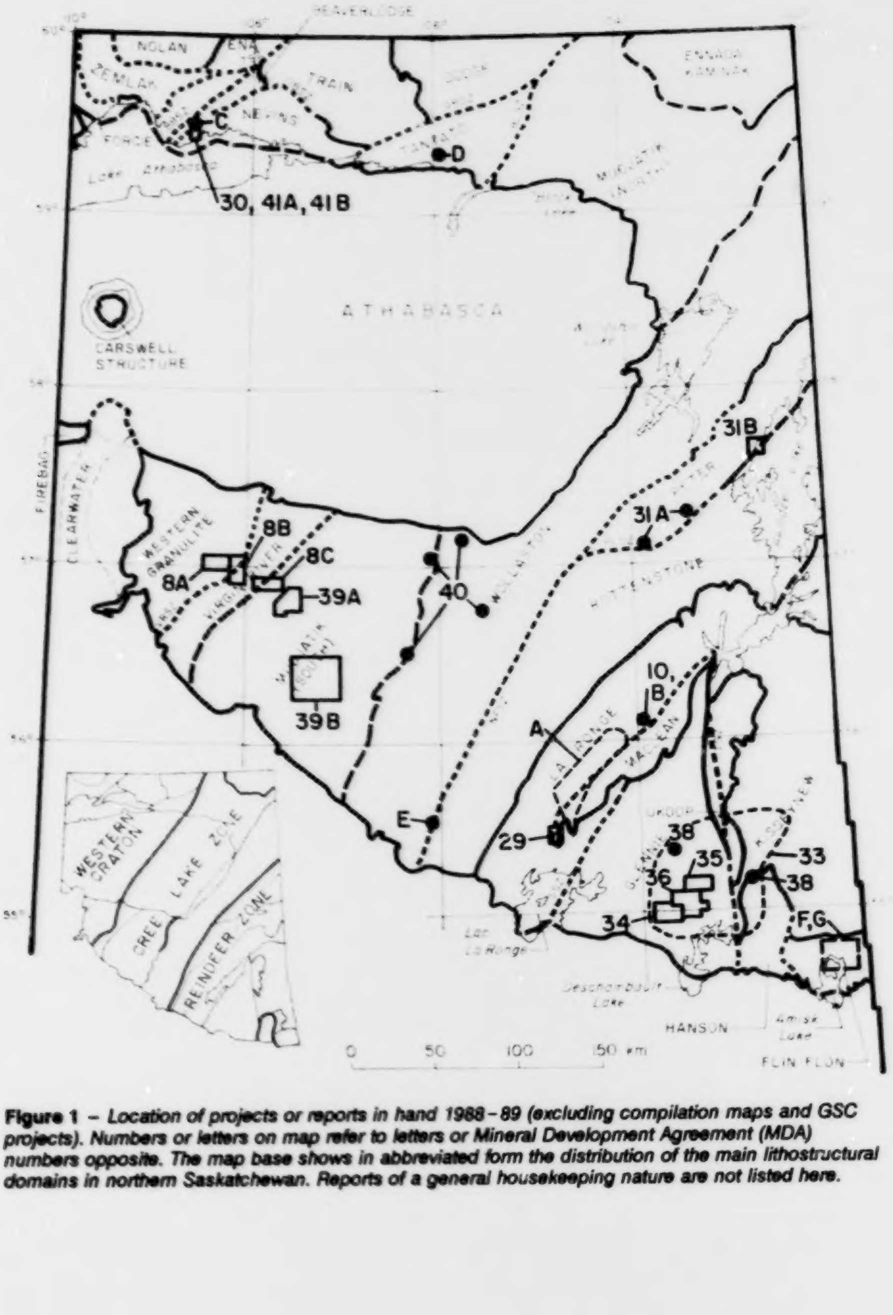
BEAVERLODGE
NOLAN
ENA
ZEMLAK
TRAIN
NEVINS
FORCE
C
D
Lake Athabasca
30, 41A, 41B
ENNADAI KAMINAK
TANTATO
ATHABASCA
CARSWELL STRUCTURE
FIREBAG
CLEARWATER
WESTERN GRANULITE
8A
8B
8C
39A
39B
40
31A
31B
WOLLASTON
ROTTENSTONE
10, B
A
LA RONGE
E
29
38
35
36
34
33
38
F,G
Lac La Ronge
Deschambault Lake
HANSON
Amisk Lake
FLIN FLON
0
50
100
150 km
WESTERN CRATON
CREE LAKE ZONE
REINDEER ZONE

Figure 1 – *Location of projects or reports in hand 1988–89 (excluding compilation maps and GSC projects). Numbers or letters on map refer to letters or Mineral Development Agreement (MDA) numbers opposite. The map base shows in abbreviated form the distribution of the main lithostructural domains in northern Saskatchewan. Reports of a general housekeeping nature are not listed here.*

Highlights of the Northern Geoscience Program 1988 – 89

R. Macdonald and T.I.I. Sibbald

Macdonald, R. and Sibbald, T.I.I. (1988): Highlights of the Northern Geoscience Program 1988 – 89; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

This year again the geoscience program in northern Saskatchewan has continued to focus largely on providing regional geological information supportive of the gold exploration play, which continues at a high state of activity. In addition, and in view of the mineral industry's long-term stake in uranium, a new project was launched in uranium geology, and studies in the platinum group metals have been continued.

MDA No.	*Proj. No.*	*Area/ Short Title*	*Project Leader(s)*	*Notes*	
A) Gold Belt Geology Program:					
1) Glennie Transect:					
34	8822	Bedrock Remapping, Brownell Lake	G.D. Delaney	1	*
35	8830	Bedrock Remapping, Gee Lake	W.L. Slimmon	1	*
36	8812	Bedrock Remapping, Paif Lake	D.J. Thomas	1	*
33	8836	P-T-t Studies	D. Perkins	1,4	
37	8821	Lithogeochemistry	B.R. Watters	0,2,3	
38	8801	Tectonic Review	J.F. Lewry/ R. Macdonald	1,4	
2) Snowbird Transect:					
8	8804	U-Pb and N-Sm Geochronology	M.E. Bickford/ K.D. Collerson	1-4	
8A	8804	Careen Lake Granulites	C.H. Crocker/ K.D. Collerson	1,4	*
8B	8804	Virgin River Shear Zone	J. Carolan/ K.D. Collerson	1,4	*
8C	8804	Black Birch area	S.E. Orrell et al.	1,4	*
3) Other:					
10	8721	Geochemistry, Central Metavolcanic Belt	B.R. Watters	6	
13	8526	Buried Precambrian, South-Central Sask.	K.D. Collerson et al.	2,6	
18	8805	Mineralized Core Collection	A.J. Gracie	1,2	
25	8810	Mineral Deposits Inventory	T. Uhrich		
29	8831	Gold Metallogeny, Sulphide Lake	D.C. Armstrong/ G.R. Parslow	1,3	
30	8832	Nicholson Bay	G.R. Parslow/ E.P.W. Peirls	1,3	
31A	8833	Campbell River Group	D.G. MacDougall	1	
31B	8833	Patterson Island Pluton	D.G. MacDougall	1	*
39A	8811	Ithingo Lake Gold	C.T. Harper	1	*
39B	8811	Porter Lake Study	C.T. Harper	1	
40	8807	Wollaston Stratigraphy	I.R. Annesley/ C.Madore	1,3	
41A	8806	Goldfields Remapping	T.I.I. Sibbald	1	
41B	8806	Goldfields Structural	R.G. Roberts/ P.H. Tyedmers	1,3	*
30	8832	Uranium Studies, Nicholson Bay	P.W. Peirls/ G.R. Parslow	1,3	
	A	Building Stone	M.W. Thomas	1,3	
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	E	Needle Falls Shear Zone	M.R. Stauffer/ J.F. Lewry	1,5	
	F	Proterozoic of Southeastern Sask.	G.R. Parslow/ J.W. Gaskarth	5,6	
	G	Till Geochemistry, East Amisk area	J.E. Campbell	5	
	H	Pt,Pd and Au in Uranium Deposits	D. Quirt	5	

(0) Report not due in 1988
(1) Field component in 1988
(2) Project covered wide area (not shown on map)
(3) Contract project in 1988
(4) Joint venture with SEM in 1988
(5) Externally contributed report
(6) Office follow-up or write-up from previous work
(*) Geological or geochemical map(s) in accompanying package

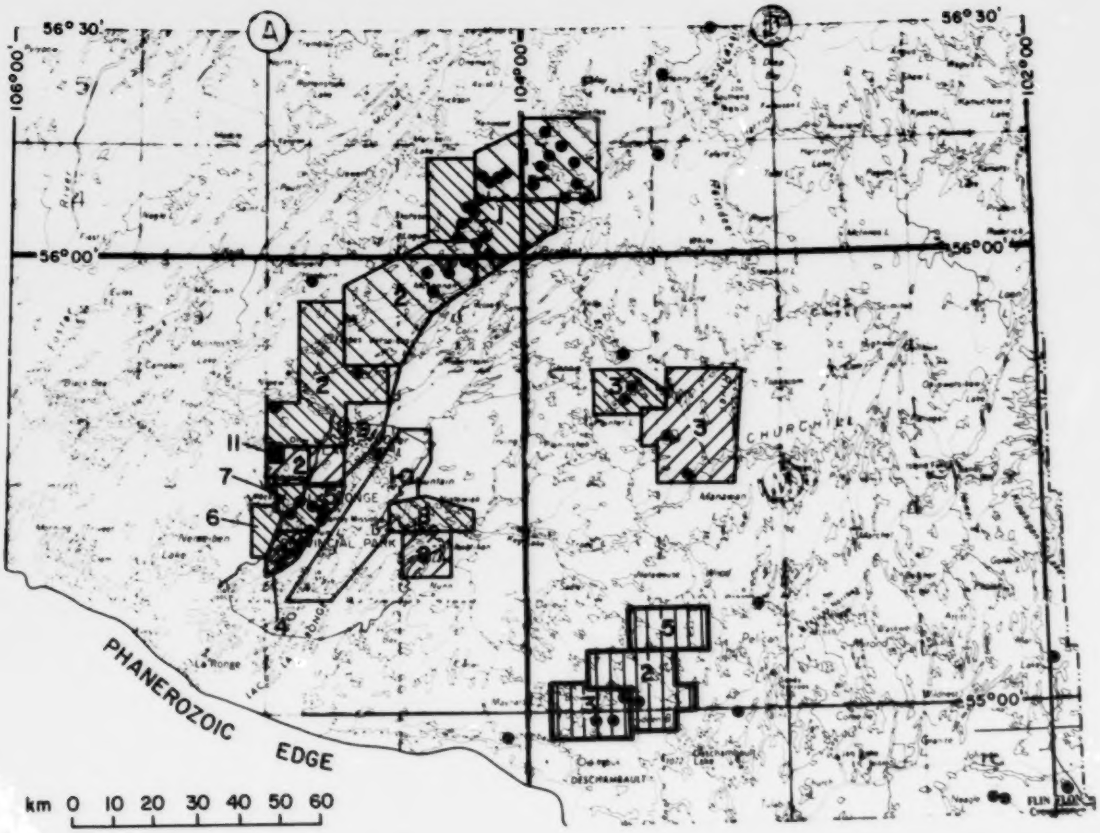

Figure 2 - Progress of bedrock remapping at 1:20,000 scale or better in the La Ronge and Glennie Domains. Dots represent approximate locations of known gold occurrences or mines.

Gold Belt Geology Program:

▧ *Remapping in 1984 and 1985*

▨ *Remapping in 1987*

▧▩ *Remapping in 1986*

▥ *Remapping in 1988*

Geologists: 1, C.T. Harper; 2, D.J. Thomas; 3, G.D. Delaney; 4, T.I.I. Sibbald; 5, W.L. Slimmon; 6, M.W. Thomas; 7, J.F. Lewry; 8, J.R. Chiarenzelli; 9, A. Abraham; 10, J.F. Lewry (1981); 11, I. Graham.

Government funding for the program was restored to the 1987-88 level by means of a student summer employment initiative, which supported the field teams, and permitted backlogs in some of the office data bases to be reduced. This year, activities have also been expanded through an increased number of joint venture projects with university and other personnel.

The majority of the projects reported in this publication have been generated wholly or in part through funding provided under the Canada-Saskatchewan Mineral Development Agreement (MDA) 1984-89, now in its fifth and final year. By this agreement, the province and federal government agreed to mount individual but coordinated geoscience programs on a 50:50 funded "parallel delivery" basis.

The provincial component of the MDA has been mainly in the form of bedrock geological remapping at 1:20,000 scale, as well as compilations and supporting lithogeochemical, isotopic, geochronological and mineral deposit studies, packaged in what is known as the Gold Belt Geology Program. Bedrock remapping of the gold belt in the La Ronge Domain was accomplished during the first four years of the MDA. This year, a start was made on an assessment of the Glennie Domain, primarily for its gold and other mineral potential, by means of bedrock remapping, structural, geochemical, P-T-t and geochronological studies, in a program known as the Glennie Transect.

The federal part of the program, undertaken by the Geological Survey of Canada, has mainly comprised regional airborne magnetic gradiometer and regional lake sediment geochemical surveys, as well as some ground geological investigations. The gradiometer surveys were flown in 1986–87 over the area lying between Flin Flon and Hanson Lake, covering the Shield edge and a large part of the terrain immediately to the south underlain by Lower Paleozoic rocks, and the results were released during the year on open file by the GSC. The federal field programs were also mainly completed last year (except for platinum-oriented studies); consequently, there is only one report of field activites from the GSC this year.

1. MDA Geoscience Program: Provincial Component

a) Glennie Transect

Bedrock Remapping, Palf Lake Area: D.J. Thomas has found that the Palf Lake area contains more metasedimentary rocks than previously thought, and less metavolcanic rocks as some have been reinterpreted as sheared dioritic plutons. The area has been subjected to polyphase deformation producing Type 2 and 3 fold interference patterns, as well as early shearing, and almost all original supracrustal structures have been destroyed. The Palf Lake greenstone is considered to be separated from the adjoining and less deformed Brownell Lake belt (see also Delaney, this volume) by a northwest-trending high-strain zone.

Exploration Targets: Many of the features of gold mineralization found in the La Ronge greenstone belt occur in this area to varying degrees. The northwest-trending high-strain zone is considered to hold the highest potential for gold mineralization. Copper mineralization occurs in calcareous metasedimentary rocks of the Palf Lake belt, but distribution is spotty.

Bedrock Remapping, Gee Lake Area: The Gee Lake greenstone belt, remapped by W.L. Slimmon, is dominated by mafic volcanics, with a minority of intermediate and felsic volcanics and volcanogenic metasediments. Pelitic metasediments overlie the volcanics to the northwest. Granitoid rocks have been assigned to parts of two major batholiths lying on either side of the east-trending greenstone belt, which is exposed as a northwest-plunging upright synform. The volcanic rocks in places display intense rodding structure.

Exploration Targets: Mineral prospects include the Hook Lake (Co-Mo-Au) and HBED (Cu-Zn-Ag-Au) zones, neither of which has been examined along strike; further work appears to be warranted. Other areas of economic interest include a north-striking lineament zone along the northwest margin of the main metavocanic exposure (west of Gee Lake) and a number of gossans in felsic volcanic rock 3 km east of Gee lake.

Bedrock Remapping, Brownell Lake Area: Remapping by G.D. Delaney in this area has demonstrated that the Brownell Lake (greenstone) belt is separated from contiguous granitod blocks by east-trending shear zones. A major syncline in meta-arkoses has been revealed in the belt, and primary structures such as cross-bedding are well preserved.

Exploration Targets: A number of gold showings occur within the margins of the Brownell Lake Pluton or in adjacent supracrustal rocks. The most favourable showings appear to be those in faults related to the major shear zones. Further examination of these faults and shear zones is suggested, particularly where they cut supracrustal rocks close to plutons.

Other Projects of the Glennie Transect: Lithogeochemical studies (B.R. Watters, University of Regina) are expected to commence this winter, using samples collected by the mapping geologists. Dexter Perkins (University of North Dakota) collected a large number of samples for P-T-t studies under a joint venture. J.F. Lewry and R. Macdonald spot-examined exposures between Keg and Pelican Lakes in an attempt to track down extensions of the protomylonitic Guncoat Gneisses or their equivalents.

b) Snowbird Transect

This program is a joint venture with the University of Kansas and the University of California, Santa Cruz campus, aimed at examining a cross-section of the Virgin River Shear Zone (in more regional terms, the Snowbird Line). The program involves field mapping by three graduate students, with emphasis on geochemistry and U-Pb/Nd-Sm isotopic and geochronological work. C.H. Crocker examined the area west of the shear zone, including the anorthositic rocks of the Western Granulite Domain. J. Carolan worked across the shear zone itself, and S.E. Orrell mapped in the Black Birch area, west of Ithingo Lake in the Mudjatik Domain. Supplemental work was done by K.D. Collerson and M.E. Bickford.

c) Mudjatik Domain

Ithingo–Porter Lakes Study: C.T. Harper has remapped part of the Ithingo Lake area, where gold was reported recently by Claude Resources, and also examined the Porter Lake area. The felsic gneisses of the Mudjatik Domain in these areas have been divided into an earlier tonalitic and layered basement, and later intrusive granites which at Porter Lake appear to have been derived by extensive anatexis. Primary volcanic features are preserved in granulite facies rocks near Ithingo Lake. The volcanic-sedimentary features, together with oxide-facies iron formation, point to continental platform and possible rift environments of deposition.

Exploration Targets: Gold mineralization in the Ithingo Lake area occurs in structurally controlled quartz veins with associated wall-rock alteration in mafic volcanics, and is interpreted to have predated granulite facies metamorphism. Elevated gold values were found also in sulphide-bearing ultramafic intrusions and calc-silicate zones in the mafic volcanics and iron formation.

Wollaston Stratigraphy: An intended three-year study was begun by I.R. Annesley (Saskatchewan Research Council), focussing on evaluation of the geology of the Wollaston Group and underlying Archean basement with respect to uranium mineralization in the Athabasca Basin. A short field progam was carried out at Beaudreau Lake, Key Lake and along the northern section of the Key Lake road. The program allowed familiarization with Wollaston Group stratigraphy, structure and metamorphism and led to recognition of a possibly significant shear zone between the Wollaston and Mudjatik Domains. Highly sheared mylonitic rocks were found at the Archean/Aphebian boundary in the Key Lake area.

d) Peter Lake Domain

Patterson Island – Campbell River Studies: D.G. MacDougall examined the Patterson Island locality and Campbell River Group this summer. The megacrystic diorite on Patterson Island is not a post-orogenic pluton as originally thought, but a conformable unit within a cumulate gabbro-diorite suite which has been infolded with extensive metavolcanics, feldspathic quartzites and arkoses. A new area of Campbell River rocks suspected from the aeromagnetic map was confirmed through an isolated bedrock exposure.

Mineral Potential: Fracture-fill and vein-type Cu-Ni-PGM south of Ant Lake are associated with hydrothermally altered gabbro and diorite. The new evidence for cumulate layering enhances the prospect for the occurrence of magmatic accumulations of these elements in the area. There is also potential for base metal mineralization through Cu-Zn occurrences in metavolcanics and iron-bearing sulphides in the quartzites and arkoses.

e) La Ronge Domain

Gold Metallogeny, Sulphide Lake: Investigations of gold deposits and their geological setting were continued in the Sulphide – PAP Lakes area by D.C. Armstong (University of Birmingham) and G.R. Parslow, (University of Regina), through lighogeochemical, stable isotope (oxygen, hydrogen and sulphur) and fluid inclusion work. Lithogeochemical data indicate that the mafic volcanics have an oceanic rift character. In contrast, the intermediate to felsic volcanics and the composite Little Deer Pluton, as well as other mafic volcanics in the La Ronge Domain, show calc-alkaline island arc affinities.

Lithogeochemical Studies: B.R. Watters (University of Regina) is presently completing work on the Central Metavolcanic Belt in collaboration with C.T. Harper and D.J. Thomas before launching into the Glennie Transect. Major plutons of the belt have now been sampled and detailed studies of the multiphase Brindson Lake Pluton are described in the report.

f) Flin Flon – Kisseynew Domains

G.R. Parslow and J.W. Gaskarth's paper on the southeastern part of the Shield is a review of their data and ideas on the geochemistry of the East Amisk *vis-a-vis* Kisseynew rocks. Research for this was funded partly under the MDA in contract and joint venture.

g) Beaverlodge Area

A study of the geology and geochemistry of uranium-gold-platinum group element mineralization in the Nicholson Bay – Fish Hook Bay area by E.P.W. Peiris and G.R. Parslow (University of Regina) is ongoing. Petrographic examinations supported by electron probe micro-analyses were conducted on ore and altered bedrock to establish parageneses of mineralization and alteration. Geochemical analyses of a wide range of rocks have been undertaken to establish elemental patterns associated with alteration and mineralization. While gold and PGE are concentrated with uranium in pitchblende veins, they also occur independently of uranium in hematized alteration zones in the basement rocks. A variety of evidence favours an unconformity-type origin for these occurrences.

The Nicholson Bay area was remapped at 1:5000 scale by T.I.I. Sibbald in conjunction with the petrographic and geochemical studies. The mapping identified new outliers of Athabasca Group in close proximity to the Nicholson no. 4 zone and defined in more detail the nature of hematitic alteration zones associated with uranium-gold-PGE mineralization and the sub-Athabasca unconformity. Arguments are also presented here to support an unconformity-type model for the mineralization.

Structural studies of the Box and Athona gold deposits at Goldfields were carried out by R.G. Roberts and P. Tyedmers (University of Waterloo), in order to determine possible structural controls of gold-quartz vein emplacement. At Athona, subvertical northerly-trending shears of similar age to the major Goldfields Syncline influence the distribution of veins, whereas at Box the immediate structural control is enigmatic, even the veins are of similar age. A later generation of "breccia veins" and fractures, containing quartz-specular hematite and local pitchblende, intersects the gold-quartz veins, altering pyrite to hematite and substantially augmenting the gold content.

h) Geochronology Update

The following U/Pb zircon dates were produced under the joint venture with the University of Kansas during the year; some of these dates are interim and require more work:

Western Granulite Domain:		
HUD-85-10	*Megacrystic gneiss, Careen Lake*	*2250 ± 59 Ma*
Mudjatik Domain:		
HUD-85-12	*Charnockitic gneiss, Jim Lake*	*1928 ± 39 Ma*

Peter Lake Domain (all from a small island on Compulsion Bay):		
HUD-85-18B	*Megacrystic tonalitic 'grey' gneiss*	*2321 ± 95 Ma*
HUD-85-18A	*Fine granitic gneiss, cutting grey gneiss*	*2390 ± 160 Ma*
HUD-85-16	*Horton Island Granite*	*1840 ± 29 Ma*
Kisseynew Domain/Hanson Lake Block:		
HUD-86-10	*Mari Lake Granodiorite*	*ca. 1850 - 1860 Ma*
HUD-86-14	*Jackpine Lake Granodiorite*	*ca. 1870 Ma*

The following U/Pb zircon dates were produced by the Geological Survey of Canada with partial support from Saskatchewan funds of the MDA (see abstract of paper in press by G.D. Delaney et al. at the rear of this volume):

Glennie Domain:	
Granodiorite, Wood Lake Batholith	*1850.8 + 5.2/-2.4 Ma*
Ourom Lake Meta-arkose, Kettle Falls (single detrital zircons)	*ca. 1853 - 1860 Ma*

A report of the buried Precambrian basement of south-central Saskatchewan by K.D. Collerson et al. provides the first published information on the petrography, isotope geology and geochronology of Precambrian deep well cores. This contribution is broadly relevant to the regional context of possible kimberlite diatremes, a subject of considerable interest in Saskatchewan at present. U-Pb zircon ages are as follows:

SASK-2	*Tonalitic gneiss, South Parkman*	*1862 ± 4 Ma*
SASK-8	*Intermediate granulite*	*1786 ± 4 Ma*
SASK-26	*Tonalitic gneiss, Musquash*	*1914 ± 50 Ma*
SASK-34	*Posttectonic granite, Cantuar*	*1763 ± 4 Ma*
SASK-35	*Charnockitic gneiss*	*2484 ± 54 Ma*
SASK-48	*Megacrystic granite gneiss, Regina*	*1822 ± 16 Ma*

Nd-Sm crustal residence ages throughout south-central Saskatchewan (12 samples) range between 2.58 to 3.36 Ga, half of them being over 3.0 Ga.

i) Bedrock Compilation and Data

The coloured version of the Mudjatik 1:250,000 sheet was publisahed during the year. The Pelican Narrows and Amisk Lake 1:250,000 scale map sheets are being extensively revised, but are not available in published form in time for this year's Open House meeting.

Although not presented in this report, the following Precambrian data files are being updated on microcomputer and may be consulted in the Regina office: Rock Sample Index, Geochronological Database, Bibliography and Lexicon.

j) Mineral Data and Compilation Maps

Two new 1:250,000 metallogenic maps, Wollaston Lake (NTS 64L) and Lac la Ronge (73P) have been published and two further sheets, Reindeer Lake South (64D) and Île-à-la-Crosse (73O), are awaiting publication. Work is presently ongoing in the Mudjatik (74B) and Cree Lake (74G) map sheets (Figure 3).

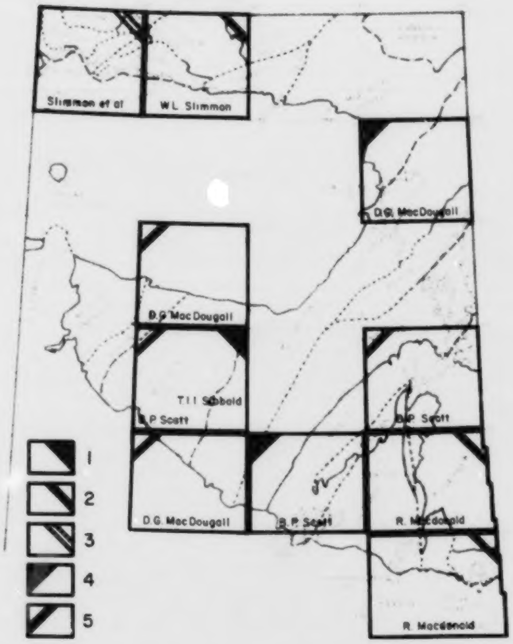

Figure 3 - Location of 1:250,000 scale compilation maps which were published or in progress in 1988 - 89: 1, Compilation Bedrock Geology final colour version published; 2, Compilation Bedrock Geology final colour version in progress; 3, Bedrock Compilation Geology black line in progress; 4, Compilation Metallogenic map published; 5, Compilation Metallogenic map in progress.

The Saskatchewan Mineral Deposits Inventory (SMDI) is essentially up-to-date in respect to information retrievable from nonconfidential assessment work records. The manual file has now been largely transferred to the microcomputer environment and various software are being investigated for data processing.

Under the mineralized core collection project, 1952 m of new core has been collected this year from mineral properties tested for gold (50 percent) base metals (33 percent) and uranium (17 percent). Stratigraphic cores totalling 1834 m were collected from holes drilled in the Athabasca and Martin Basins, as well as in Paleozoic rocks overlying the southeastern part of the Shield.

2. MDA Geoscience Program: GSC Studies

Most of the GSC field work for projects under the MDA was completed in the summer of 1987 and the reports are presently being compiled.

Larry Hulbert continued investigations into PGE through examination of mafic and ultramafic bodies in the Stony Rapids, Axis Lake and Currie Lake areas north of Lake Athabasca. Although these granulite facies bodies do not contain economic concentrations of PGE, they do show some potential for Ni-Cu-Co mineralization. Diabase dykes of MacKenzie type and hydrothermal Au-PGE mineralization in the Greater Beaverlodge area are also subjects of continuing studies. Geochronological U-Pb and Nd-Sm data and electron microprobe mineral composition from a variety of mafic-ultramafic intrusions are presented. Notably, a diabase sill at Tremblay Lake has yielded a U-Pb date of 1265 ± 1 Ma on baddleyite, in close agreement with other Athabasca Basin Rb-Sr diabase ages of 1227 ± 11 Ma reported by D. Quirt.

3. Other Northern Studies (Non-MDA)

Reports have been contributed on precious metal geochemistry (C.E. Dunn, GSC), the origin of the Frontier Granite (E.H. Appleyard), and the first detailed study of the Needle Falls Shear Zone at the type locality on the Churchill River (M.R. Stauffer and J.F. Lewry).

The Saskatchewan Research Council has provided a report on the Quaternary geology of the East Amisk area by J.E. Campbell which is a follow up last year's field work.

An investigation was undertaken by D. Quirt (SRC) of the gold and PGE content of Athabasca Basin uranium deposits and other geological environments, including the Athabasca and Martin Groups and the Goldfields area gold deposits. No significant PGE enrichments were detected in any of these environments; neverthless, elevated levels of gold were noted in association with unconformity-type uranium mineralization and in some samples from the Martin Group. Quirt also reports on a Rb-Sr age of 1227 ± 11 Ma for Mackenzie diabase dykes cutting the Athabasca Group (Armstrong et al., in prep.)

E.H. Appleyard (University of Waterloo) reports on lithogeochemical data obtained by D. Quirt (SRC) from the Frontier gold prospect in the Goldfields area. Analyses of the Frontier granite (the host to gold-quartz vein mineralization), the surrounding quartzites and rocks transitional between the granite and quartzite have been examined utilizing Gesens (1967) general metasomatic equation. Granitization is suggested as a possible model for derivation of the Frontier granite from the surrounding quartzites, but it requires a doubling of volume and the existence of a low-viscosity hydrous magma. Au, Cr, S and As may have been added in the granitization process and later introduced into the gold-quartz veins.

Provincial Projects in Northern Saskatchewan Under the Canada – Saskatchewan MDA 1984 – 89

Project 8822

Bedrock Geological Mapping, Brownell Lake Area (Part of NTS 63M-4 and 63L-13)[1]

G.D. Delaney

Delaney, G.D. (1988): Bedrock geological mapping, Brownell Lake Area (part of NTS 63M and 63L-13); *in* Summary of Investigation 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

This report documents the preliminary results of revision mapping at a scale of 1:20,000 of approximately 240 km^2 in the area surrounding Brownell Lake (NTS 63M-4 and 63L-13). This mapping is part of a detailed transect of the southern Glennie Lake Domain, Trans-Hudson Orogen. Mapping in contiguous areas to the east and north is reported on elsewhere in this volume (W.L. Slimmon; D.J. Thomas).

1. Previous Work

Early reconnaissance geological investigations included those of McInnes (1913) and DeLury (1926). During the period 1963 - 1966, Padgham (1968) mapped the Brownell Lake area at a scale of 1:31,680 as part of larger scale 1:63,360 mapping that included map sheets 63L-13, 63L-14(W) and parts of 63L-11 and -12. In 1975 and 1976, Scott (1981) mapped NTS sheets 63M-4 and 63M-3(W) at a scale of 1:63,360.

The northern part of the area is contained in Taylor's (1958) 1:253,440 compilation map of the bedrock geology of the Pelican Narrows area (NTS 63M). The entire map area lies within a more recent 1:250,000 compilation map of the bedrock geology of the Amisk Lake and Pelican Narrows areas (Macdonald, 1981).

In 1974, the map area was included in a reconnaissance lake sediment geochemical survey undertaken by the Geological Survey of Canada (Hornbrook et al., 1975, 1977, 1985).

The project area is covered by Geological Survey of Canada 1:63,360 scale aeromagnetic maps 4822G (63M-4)and 4593G (63L-13) and 1:250,000 scale aeromagnetic maps 7764G (63M) and 7754G (63L).

2. Regional Geology

The map area is located in the southern part of the Glennie Lake Domain, a key component of the Lower Proterozoic Trans-Hudson Orogen. The Glennie Lake Domain is characterized by subordinate, narrow, commonly arcuate belts of metavolcanics and metasediments in granitoid rocks. The domain has been interpreted as being the remnant of one or more Lower Proterozoic arc terranes which, together with minor incorporated Archean basement, collided with the adjacent La Ronge Domain (Lewry, 1981; Lewry et al., 1987; Chiarenzelli et at., 1987). This model is based on detailed remapping along the northwestern margin of the domain, coupled with a synthesis of known geological data for the rest of the domain. In particular, there is limited information about the character and history of the southern Glennie Lake Domain, although a collation by Lewry et al. (1978) noted a general decrease in metamorphic grade from north to south in the domain.

3. General Geology

The map area comprises four distinct lithotectonic elements which are termed the Oskikebuk Block, Brownell Lake Greenstone Belt, Carroll Lake Block and Kvamsing Cataclastic Belt (Figure 1). The first three names or variations of them have been used previously in compilation maps and summary reports of the Precambrian geology of northern Saskatchewan (i.e., Macdonald, 1981, 1987). The northern margin of the Oskikebuk Block forms the southern boundary of the map area and is separated from the Brownell Lake Greenstone Belt by the east-trending Hartley Shear Zone.

The Brownell Lake Greenstone Belt comprises both supracrustal and granitoid rocks which have been subjected to amphibolite facies metamorphism. Supracrustal rocks are divided into two main assemblages: the Brownell Lake Group and the Wapawekka Lake Formation of the Wapawekka Group (Padgham, 1968). The Brownell Lake Group, in the eastern part of the area, comprises both volcanic and sedimentary rocks. Volcanic rocks include mafic to intermediate flows, associated intrusives and volcaniclastic rocks which predominate over felsic volcaniclastics and felsic volcanics. Pelitic schists with minor intercalated conglomerates are the main sedimentary rocks. The Wapawekka Lake Formation, in the western part of the map area, consists mostly of arkose with locally abundant plagioclase porphyry sills and minor intermediate volcanics and volcaniclastics.

There are several distinct granitoid bodies in the Brownell Lake Greenstone Belt. An early diorite and quartz monzodiorite intrusive lies south of the eastern end of Brownell Lake. Other small intrusions are composed of tonalite to granodiorite or porphyritic granodiorite. The Brownell Lake Greenstone Belt is cut by two later composite plutons, the Brownell Lake and Maynard

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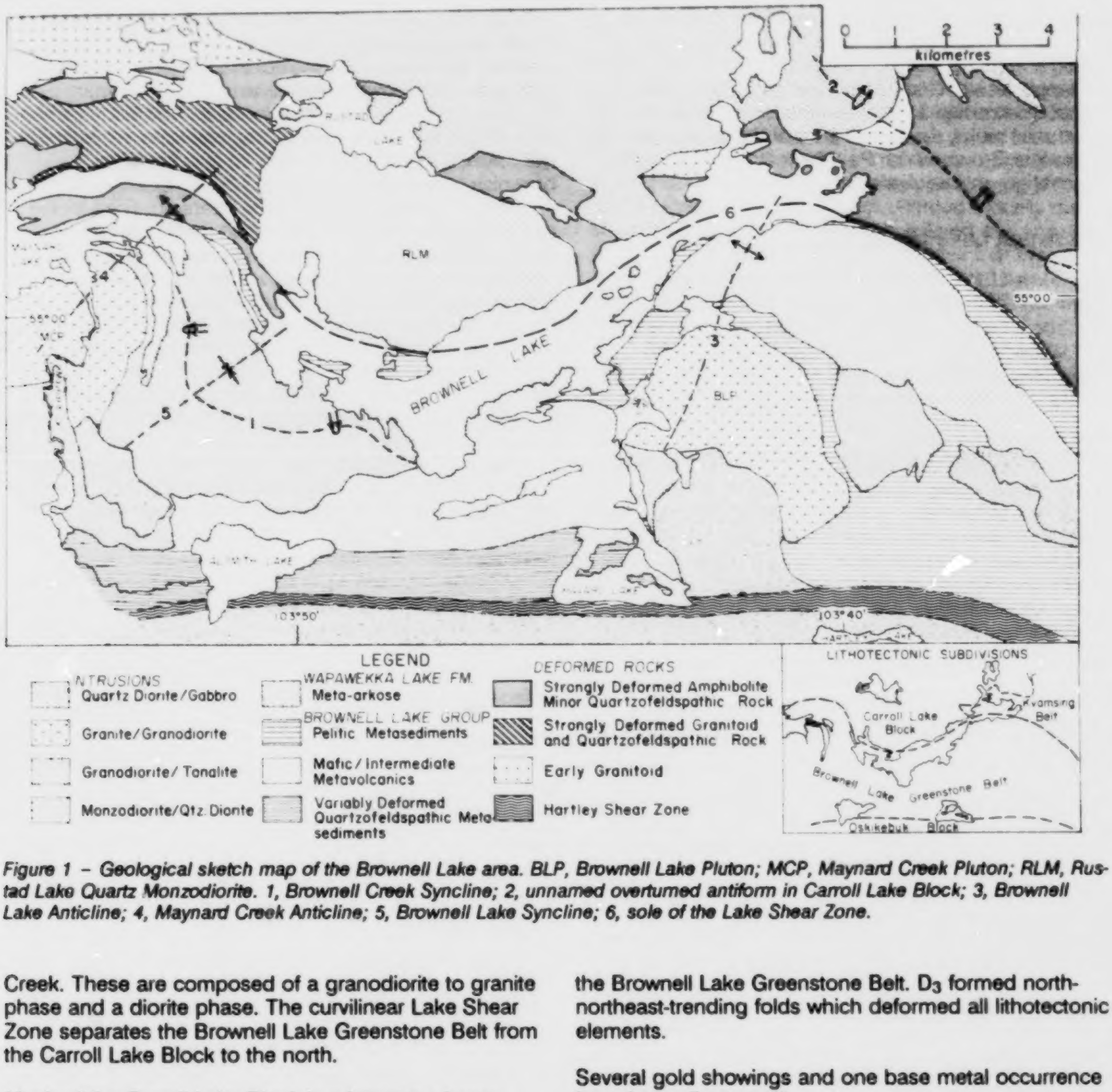
(1) Project funded under the Saskatchewan component of the Canada - Saskatchewan Subsidiary Agreement on Mineral Development 1984 - 89



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kilometres
RUSTAD LAKE
RLM
BROWNELL LAKE
BLP
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1
2
3
4
5
6
LEGEND
INTRUSIONS
Quartz Diorite/Gabbro
Granite/Granodiorite
Granodiorite/Tonalite
Monzodiorite/Qtz Diorite
WAPAWEKKA LAKE FM.
Meta-arkose
BROWNELL LAKE GROUP
Pelitic Metasediments
Mafic/Intermediate Metavolcanics
Variably Deformed Quartzofeldspathic Metasediments
DEFORMED ROCKS
Strongly Deformed Amphibolite Minor Quartzofeldspathic Rock
Strongly Deformed Granitoid and Quartzofeldspathic Rock
Early Granitoid
Hartley Shear Zone
LITHOTECTONIC SUBDIVISIONS
Carroll Lake Block
Kvamsing Belt
Brownell Lake Greenstone Belt
Oskikebuk Block

Figure 1 - Geological sketch map of the Brownell Lake area. BLP, Brownell Lake Pluton; MCP, Maynard Creek Pluton; RLM, Rustad Lake Quartz Monzodiorite. 1, Brownell Creek Syncline; 2, unnamed overturned antiform in Carroll Lake Block; 3, Brownell Lake Anticline; 4, Maynard Creek Anticline; 5, Brownell Lake Syncline; 6, sole of the Lake Shear Zone.

Creek. These are composed of a granodiorite to granite phase and a diorite phase. The curvilinear Lake Shear Zone separates the Brownell Lake Greenstone Belt from the Carroll Lake Block to the north.

Much of the Carroll Lake Block is a late-stage leucocratic granodiorite. Near the southern margin of this intrusive is a discontinuous belt of older granitoid, supracrustal and cataclastic rocks that are correlative with those in the Kvamsing Cataclastic Belt. The Rustad Lake Quartz Monzodiorite forms the southern margin of the Carroll Lake Block.

Most of the Kvamsing Cataclastic Belt comprises moderately to generally strongly deformed amphibolitic rocks which probably had a basic intrusive protolith.

Three episodes of deformation are recognized. The first, D_1, formed cataclastic rocks that underlie most of the Kvamsing Cataclastic Belt and are preserved as remnants in the Carroll Lake Block. The second deformation, D_2, formed east-trending overturned folds in the Brownell Lake Greenstone Belt and Carroll Lake Block. This event was probably synchronous with thrusting of the Brownell Lake Greenstone Belt. D_3 formed north-northeast-trending folds which deformed all lithotectonic elements.

Several gold showings and one base metal occurrence have been discovered.

4. Oskikebuk Block

The northern part of the Oskikebuk Block is composed of medium-grained mesocratic diorite (unit OLbd). The northern boundary of the block is progressively deformed with an increasingly strong east-west planar fabric that merges into mylonites of the Hartley Shear Zone. Within this northerly-dipping shear zone are both amphibolitic (unit OLbx) and quartzofeldspathic (unit qfx) mylonites.

5. Brownell Lake Greenstone Belt

The Brownell Lake Greenstone Belt is bounded on the south by the Hartley Shear Zone, and on the north by the curvilinear, generally narrow Lake Shear Zone which largely traces through Brownell Lake. This shear is exposed on a few islands and at both ends of the lake.

The Brownell Lake Greenstone Belt contains granitic rocks of at least two ages and two assemblages of supracrustal rocks, the Brownell Lake Group and the Wapawekka Group, which Padgham (1968) interpreted to be stratigraphic equivalents.

a) Brownell Lake Group (BL)

The Brownell Lake Group, which underlies much of the eastern part of the Brownell Lake Greenstone Belt, consists of both metavolcanic and metasedimentary rocks. In the volcanic suite, basic to intermediate metavolcanics and associated metavolcaniclastics are most common and felsic phases are minor.

Mafic to Intermediate Metavolcanics (Unit BLvb):

Mafic to intermediate metavolcanics form a thick mass south of the central part of Brownell Lake. The main phase in this sequence is fine-grained dark green amphibolite; other phases include fine- to medium-grained hornblende granitoid, gabbro and compositionally layered volcaniclastics. Extensive cover, coupled with locally extreme deformation (e.g., the strong rodding along the south side of Brownell Lake), masks primary structures in much of this sequence and in some cases makes it hard to trace along individual units. Only locally have primary structures such as pillows and breccias been observed.

Quartzofeldspathic Metasediments and Cataclastic Derivatives (Unit BLvn):

In a belt stretching from Havard Lake to the east side of Alsmith Lake, there is a complex assemblage of variably deformed and mostly fine-grained quartzofeldspathic rocks of probable felsic volcanic or volcaniclastic origin. Unfortunately, the low swampy ground that lies along much of this belt obscures relationships. Constituent phases in this belt include:

1) thin bedded, light grey, fine-grained quartzofeldspathic rocks, including some semipelitic varieties that underlie the island on Havard Lake;
2) a fine-grained grey to light grey biotite-quartz-feldspar rock that is exposed on the west shore of Havard Lake; this rock is characterized by a pronounced lineation and a local vague compositional layering;
3) amphibolitic and felsic mylonites that are found along much of the northern boundary of the belt and are particularly well exposed in the area flanking Alsmith Lake; typically these rocks consist of layered fine-grained streaky hornblendic mylonites with felsic streaks and millimetre- to centimetre-thick layers of felsic mylonite; and
4) calc-silicate-bearing lenses.

Pelitic Metasediments (Unit BLpl):

Garnet-biotite-staurolite schist (BLpls) is the main type of metasedimentary rock in the Brownell Lake Group. Subordinate rock types are muscovite-biotite schist, garnet-biotite schist and sillimanite schist. Staurolite schist occurs in a thin strip along the southern shore at the northeast end of Brownell Lake, flanks the northern margin of the Brownell Lake Pluton and forms a large body to the west of this feature. Most typically, staurolite schist is a well-foliated, commonly crenulated and brown to brownish-grey rock characterized by centimetre-size euhedra of staurolite, medium- to coarse-grained biotite and fine- to medium-grained garnet in a fine-grained quartz-feldspar matrix. Original compositional layering is preserved locally in this variety. In some places, garnetiferous biotite schist layers alternate with layers containing abundant staurolite and only minor fine-grained garnet. In the large mass of staurolite schist on the north side of Hartley Lake, another variant (BLpls1) is a strongly foliated fine-grained rock containing fine-grained biotite, garnet and fine- to locally medium-grained staurolite.

A belt of strongly foliated garnet-mica schist flanks the northeast margin of the Brownell Lake Greenstone Belt.

Rare occurrences of sillimanite were noted in pelitic schist of the Brownell Lake Group. In some of these, fibrolitic sillimanite appears to occur in bladed pseudomorphs similar to kyanite.

Another component of the schist sequence is biotite-feldspar crystal schist (subunit BLplp). This subunit is characterized by tabular to rounded plagioclase crystals 1 to 3 mm in size forming as much as 60 percent of the rock, in a fine-grained biotitic quartzofeldspathic matrix. In some outcrops, crystal schist is present only in a single layer; elsewhere, several feldspar crystal layers are intercalated in biotite schist.

Pebble Metaconglomerate (Unit BLo):

A few polymictic pebble conglomerate horizons are intercalated in the staurolite and/or biotite schist. This unit ranges in thickness from a few tens of centimetres to a maximum of 3 m. A variety of clasts are present, including granitoid, as well as felsic to mafic volcanic rocks. In exposures near Brownell Lake, clasts exhibit a pronounced elongation, taking on the shape of extremely stretched ellipsoids.

b) Wapawekka Lake Formation (WL)

The western part of the Brownell Greenstone Belt is underlain by arkose and minor volcanics as well as volcaniclastics of the Wapawekka Lake Formation, Wapawekka Group (Padgham, 1968).

Meta-arkose (Unit WLr):

Meta-arkose is light grey to buff and composed mostly of feldspar and quartz in various ratios. Minor but variable amounts of biotite, muscovite and magnetite also occur. Minor grit units are present. Southeast of Maynard Lake, where this unit is less deformed, it is typically thin to medium bedded; trough crossbedding was observed at several localities. A detailed analysis of these structures revealed that the meta-arkose lies in the core of a previously unrecognized, overturned, east-trending syncline, here named the Brownell Creek Syncline. Where meta-arkose wraps around the north side of the Maynard Lake Pluton, this unit has been significantly thinned and no primary structures are preserved.

Plagioclase Porphyry (Unit WLp):

Along the southern margin of the Brownell Creek Syncline, there are several sills of plagioclase porphyry in the meta-arkose. The plagioclase porphyry is characterized by medium- to rarely coarse-grained phenocrysts of plagioclase in a fine-grained groundmass composed of quartz, feldspar and biotite. Individual sills range in thickness up to a few metres and are typically foliated. The greatest concentration of sills is between the southeast arm of Maynard Lake and Alsmith Lake.

Intermediate Metavolcanics and Metavolcaniclastics (unit WLvw):

A thin sequence of trachytic andesite, conglomerate and thin-bedded tuff flanks the meta-arkose on the northern margin of the Brownell Creek Syncline. Only rare tectonic wedges of this unit were found near the southern margin of the syncline.

c) Granitoid Rocks

There are several distinct intrusive bodies in the Brownell Lake Greenstone Belt.

Quartz Monzodiorite (Unit gqb1) and Quartz Diorite (Unit bd1):

South of the northeast arm of Brownell Lake is a lunate-shaped intrusive that consists of an irregular peripheral zone of quartz monzodiorite (gqb1) to rare tonalite that mantles quartz diorite to diorite (bd1) (Figure 2a). Although parts of this intrusion are apparently massive, more typically it is characterized by one and in places two well-developed foliations and a pronounced intersection lineation.

Composite Granodiorite to Tonalite Intrusion (Units gd1 and gd2):

Approximately 3 km north of Hartley Lake, an elliptically shaped granitoid consists of two distinct phases. The eastern half of this body is composed of medium-grained leucocratic granodiorite, tonalite and quartz diorite (gd1; Figure 2b). The western half is a leucocratic granodiorite which is generally medium grained, except along its eastern boundary where there is a distinct fine-grained phase (gd2; Figure 2c).

Plagioclase Porphyritic Granodiorite (Unit gdp):

On the east shore of the north-trending lake immediately north of Havard Lake is a small mass of plagioclase porphyritic granodiorite.

d) Brownell Lake Pluton (Unit BLgdp)

The Brownell Lake Pluton (Padgham, 1968) is a pinkish-buff medium-grained granite to granodiorite (Figure 2d). The pluton contains phenocrysts of microcline which are typically subhedral to euhedral, as much as 3 cm long and commonly rimmed by a thin veneer of plagioclase. The amount of phenocrysts varies, and rare exposures are completely devoid of them. Although locally massive, more typically this pluton is foliated and lineated; an analysis of these structures indicates that the pluton lies in the nose and on the eastern limb of a north-northeast-trending antiform which Padgham (1968) named the Brownell Lake Anticline.

Diorite to Gabbro (Unit BLbd) and Associated Hypabyssal Phases (Unit BLbd1):

South of the Brownell Lake Pluton, and separated from it by a curvilinear fault zone with some smeared wedges of schist, is a basic granitoid body composed of two distinct phases. The major phase is dark green, medium-grained, massive, mesocratic diorite to gabbro (BLbd). Along the east side is a more heterogeneous assemblage of hypabyssal phases characterized by medium- to coarse-grained porphyroblasts of hornblende in a fine-grained matrix (BLbd1). The close spatial association of this basic intrusive with the Brownell Lake Pluton suggests that the two are probably related.

e) Maynard Creek Pluton (Unit MCgd)

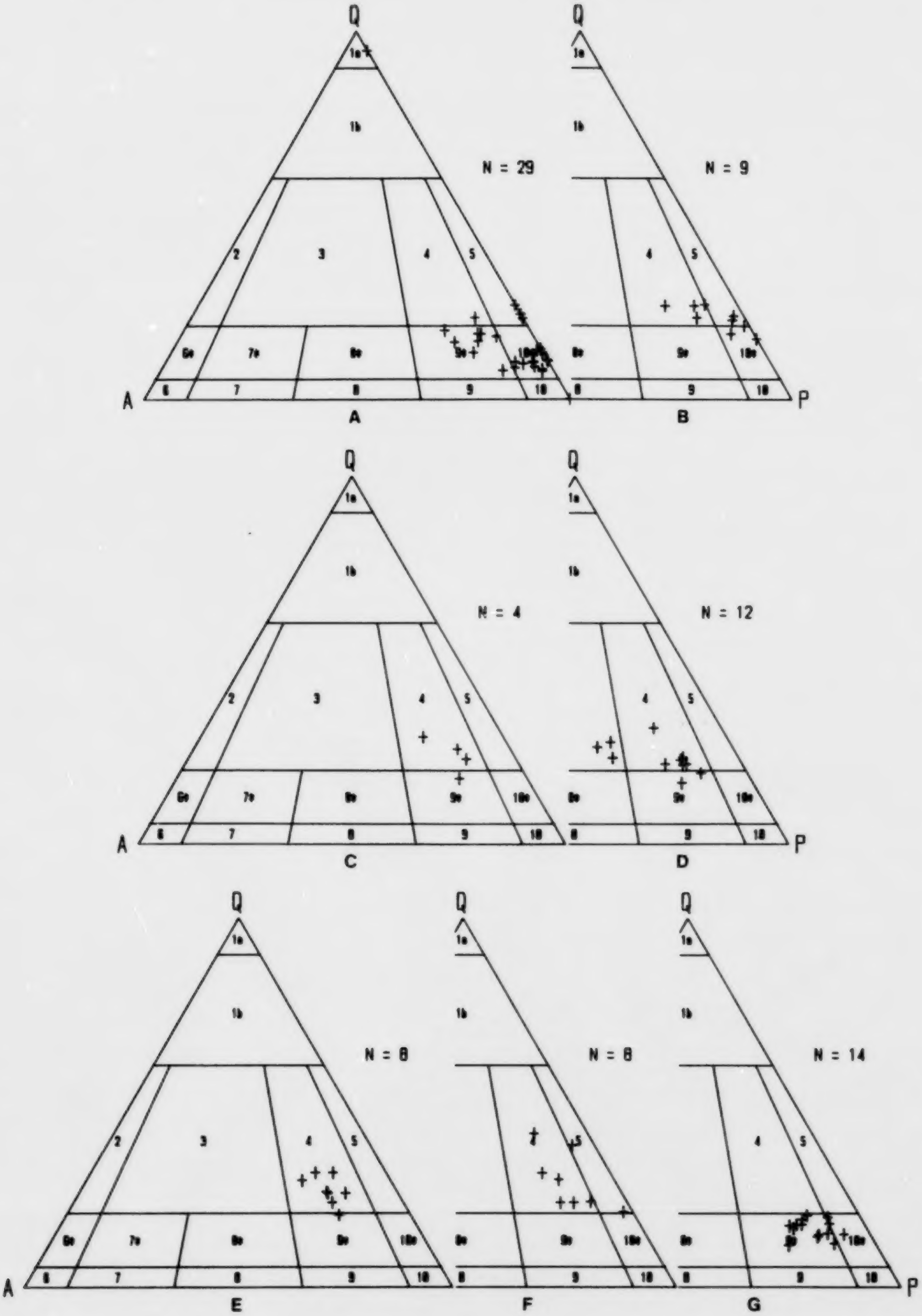
South of the east end of Maynard Lake, another granitoid body is not only similar in composition to the Brownell Lake Pluton, but also has an associated basic phase. This intrusion, the Maynard Creek Pluton (ibid.), is a buff to pinkish buff medium-grained leucocratic granodiorite (Figure 2e). Inclusions of a grey basic rock are common near its margins. The granodiorite is typically foliated and lineated; an analysis of these structures reveals that, like the Brownell Lake Pluton, the Maynard Creek Pluton occupies the nose of a northeast-trending antiform, the Maynard Creek Anticline (ibid.).

Diorite to Quartz Diorite (Unit MCbd):

Diorite to quartz diorite (MCbd) is present at the south end of the Maynard Creek Pluton. This phase is characterized by textural and compositional variations. The main body is typically mesocratic, containing various proportions of hornblende and biotite. Some phases are medium grained and massive; others contain scattered medium-grained phenocrysts of hornblende in a fine-grained groundmass of plagioclase and mafic minerals.

Porphyritic Diorite (Unit MCbdp):

East of Maynard Creek is a small body of porphyritic diorite (MCbdp). This typically foliated phase is characterized by coarse-grained phenocrysts of plagioclase and rarely hornblende in a leucocratic to mesocratic groundmass of biotite, hornblende and plagioclase. A small lens of ultramafic (MCu) rock lies at the eastern margin of this basic intrusive.


Q
1a
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6. Carroll Lake Block

Much of the Carroll Lake Block is a late-stage leucocratic granodiorite that hosts remnants of older granitoid, supracrustal and cataclastic rocks, most of which lie in a semicontinuous, irregular belt near the southern margin of the block. Xenoliths or small screens of many of the older rocks are also found elsewhere in the granodiorite. The belt of older rocks is in partial continuity with those in the Kvamsing Cataclastic Belt, and the boundary between the two (Figure 1) was somewhat subjectively drawn. A monzodiorite intrusive forms the southern part of the Carroll Lake Block.

a) Older Granitoid, Supracrustal and Cataclastic Rocks

Included in this assemblage is a variety of rock types, some of the more common of which will be briefly described here. Fine-grained strongly foliated leucocratic quartzofeldspathic gneiss (n1) flanks the narrows of the arm of Brownell Lake leading to the connector lake with Kvamsing Lake. Another variety, occupying the nose of the eastern terminus of the Carroll Lake Block, is a strongly foliated and lineated, generally leucocratic fine-grained granodiorite (n2). Fine-grained dark green amphibolite (mx), which is also found along the belt, is typically characterized by a paper-thin, closely spaced foliation with late fine-grained pinhead garnets. As in the Kvamsing Cataclastic Belt, layers of varying thicknesses of sheared and mylonitized fine-grained quartz-feldspar rock (mqx) occur with the amphibolite. This latter component also is found as a distinct and separate unit of grey, fine-grained quartzofeldspathic rock (qx) containing minor biotite as well as trace amounts of magnetite and garnet. West of Rustad Lake, flanking the northern shores of the adjacent large lake, is a distinctive quartzofeldspathic paragneiss (n3) characterized by centimetre-sized composite quartz grains.

b) Granitoid Rocks

Late Granodiorite (Unit gd3):

The most abundant granitoid is a late granodiorite (Figure 2f). This rock is texturally variable. Near the southern end of the Carroll Lake Block between Brownell and Kvamsing Lakes, this granodiorite is typically buff, medium-grained and foliated, and contains a few percent epidotized biotite and disseminated magnetite. Composite quartz grains up to 5 mm in diameter are common; in some outcrops these have a distinctive reddish stain. Further to the east, in an antiformal closure near the margin of the Carroll Lake Block, the granodiorite is a buff to pinkish buff, moderately foliated and strongly lineated rock. This lineation is defined by elongate quartz grains up to 10 mm in length. To the west, in the area north of Rustad Lake, the granodiorite is a buff foliated rock which, although similar in composition to varieties to east, is generally finer grained.

Rustad Lake Quartz Monzodiorite (Unit RLgqb):

South of the discontinuous belt of granitoid, supracrustal and cataclastic rocks along the southern margin of the granodiorite (gd3) is a quartz monzodiorite intrusion (Figure 2g) that was previously named the Rustad Lake Granite (Macdonald, 1981) but is here renamed the Rustad Lake Monzodiorite because of new, more detailed petrological information. Most of this intrusion is a buff to grey, medium-grained, foliated and lineated mesocratic rock characterized by a somewhat patchy distribution of microcline. Near the northern margin of the intrusion is a leucocratic tonalite to quartz monzodiorite phase characterized by scattered but rare porphyroblasts or clots of hornblende. The southern margin of this intrusion is similarly heterogeneous and includes syenodiorite and monzodiorite phases. To the west, near the hinge of the Maynard Creek Anticline, this granitoid is progressively deformed and merges into mylonitic zones.

7. Kvamsing Cataclastic Belt

The Kvamsing Cataclastic Belt comprises an assemblage of rocks that, for the most part, have been subjected to severe cataclasis. The most common rock type is dark green, fine-grained, strongly foliated amphibolite (Kmx) which typically contains pinhead garnets. In some parts of the belt, amphibolites contain foliation-parallel layers of a buff to light grey, strongly foliated, leucocratic and very fine grained quartz-feldspar rock. Although some of these mixed intervals are narrow, the mixed rocks elsewhere are distinguished as a separate lithologic subdivision (Kmqx) on the accompanying map. In addition to the mixed amphibolitic and quartzofeldspathic rocks, there are narrow but mappable, very fine grained, buff to light grey, strongly foliated quartzofeldspathic rocks (Kqx). Locally, these contain porphyroblasts of strongly flattened and rodded garnet; in some exposures this unit has a distinctive mottled character.

The northeast corner of the map area is underlain by a medium- to locally coarse-grained, dark green, mesocratic to melanocratic gabbro to diorite (Kbd) that is locally dissected by narrow shear zones. To the south, this intrusive has developed a progressively stronger foliation which is accompanied by a reduction of grain size; the rock is indistinguishable from the widespread, fine-grained, strongly foliated amphibolite. At a few localities elsewhere in the Kvamsing Cataclastic Belt, there are small remnant lenses of gabbro or diorite. Such a relationship suggests that basic intrusive

Figure 2 - Modal compositions of intrusive phases, Brownell Lake area. Compositions were determined by visual estimates with a binocular microscope of stained hand samples. A, units gqb1 and bd1; B, unit gd1; C, unit gd2; D, Brownell Lake pluton unit BLgdp; E, Maynard Creek Pluton unit MCgd; F, unit gd3; G, Rustad Lake Quartz Monzodiorite unit RLgqb. Subdivision names on triangular diagrams: 3, granite; 4, granodiorite; 5, tonalite; 8, quartz monzonite; 9*, quartz monzodiorite/quartz monzogabbro; 10*, quartz diorite/quartz gabbro; 8, monzonite; 9, monzodiorite/monzogabbro; 10, diorite/gabbro/anorthosite (after Streickeisen, 1976).*

rocks are probably the protolith for much of the amphibolite.

Southeast of the southern end of Kvamsing Lake, there is a very distinctive lens of granodiorite. This rock is light grey to buff light grey (Kgd1), medium grained and composed of 35 to 40 percent quartz, 7 percent biotite and minor garnet. The quartz occurs in composite grains that weather in a distinctive knobby fashion. Near the southern margin of the Kvamsing Belt, there are two small bodies composed of mostly medium-grained tremolite-actinolite. A distinctive gossan zone is developed in outcrops of this unit (Kuc).

Along the eastern margin of the map area, the Kvamsing Cataclastic Belt is segmented by the northeastern end of the Hidden Bay Pluton (Unit HBgd; ibid.). This intrusion is a pinkish buff, medium-grained leucocratic granodiorite that is both foliated and lineated; later pink felsite veinlets cut the granodiorite.

The Hidden Bay Pluton is probably a distinct lithotectonic element but not enough of it lies within the map area to warrant further discussion here.

8. Structural Geology

Three deformation events have affected the map area. The oldest deformation, D_1, has only been distinguished in the older rocks in the Carroll Lake Block and in Kvamsing Cataclastic Belt. The episode of cataclasis associated with this event formed the mylonites and associated strongly deformed rocks of the Kvamsing Cataclastic Belt and in correlative rocks of the Carroll Lake Block.

The second deformation event, D_2, resulted in both significant folding and faulting. The major shear zones that bound the Brownell Greenstone Belt, the Hartley Shear Zone along the south and the Lake Shear Zone at the northern margin of the greenstone belt, formed during this episode, as did the east-trending overturned Brownell Creek Syncline. In addition, other smaller folds probably formed during this episode, such as the one in the pelites north of Hartley Lake. D_2 folding was also responsible for the development of a pervasive foliation in most of the granitoid and supracrustal rocks of the Brownell Lake Greenstone Belt, as well, probably, as the development of L-tectonites in supracrustal rocks along the southern shore of Brownell Lake. East-trending faults, such as those in the Brownell Lake volcanics north of Havard Lake, are interpreted as minor thrust faults related to development of the Hartley Shear Zone. In the Carroll Lake Block, D_2 folding deformed the late granodiorite into an east-southeast-trending overturned antiform.

The D_3 deformation formed a series of northeast-trending folds that include the Maynard Creek Anticline, the Brownell Lake Anticline and the Brownell Lake Syncline previously recognized by Padgham (1968), as well as other unnamed folds such as the small antiform near the eastern end of the Brownell Creek Syncline and the antiformal structure between the Carroll Lake Block and the Hidden Bay Pluton. The effects of this folding, including the folding of an earlier foliation and the development of a pervasive lineation, are pronounced in the Brownell Lake Greenstone Belt, as well as in that part of the Kvamsing Cataclastic Belt mantling the greenstone belt and in the Rustad Lake Quartz Monzodiorite in the southern margin of the Carroll Lake Block. The effect is somewhat muted in the main granodiorite phase of the Carroll Lake Block, where there are only minor flexures of the earlier D_2 foliation. Similarly, D_3 folding is less widespread in the northern part of the Oskikebuk Block, although at least locally, as east of Alsmith Lake, both Oskikebuk rocks and the Hartley Shear Zone have been deformed into a northeast-trending fold.

Within the intrusive phases in the core zones of the Brownell Lake Anticline, narrow discontinuous shear zones cut all earlier fabrics. These are interpreted as representing a late stage of D_3 deformation.

9. Age Dating

To date there are no U-Pb zircon age determinations from the map area and only two such age determinations have been made on samples collected from sites nearby. One sample, HUD 83-6, described as gneiss of the Carroll Lake Complex and collected from the south side of Carroll Lake, yielded a date of 1893 ± 35 Ma (Van Schmus and Bickford, 1984). Although this sample comes from the Carroll Lake Block, its geological context is not well understood. The second date, 1881 ± 6 Ma (ibid.), was for sample HUD 83-7, metarhyolite from the north side of Palf Lake about 25 km east of Brownell Lake. The relationship between this volcanic rock and those at Brownell Lake has not been established.

In order to better understand the timing of events in the map area, a suite of four samples was collected for U-Pb age determinations by R. Parrish at the geochronology laboratory, Geological Survey of Canada. Samples collected for dating are: 8822-375, younger granodiorite from near the eastern end of the Carroll Lake Block (unit gd3); 8822-376, meta-arkose from the Wapawekka Lake Formation (unit WLr); 8822-377, granite from the Brownell Lake Pluton (unit BLgdp); and 8822-378, granodiorite from the Maynard Creek Pluton (unit MCgd).

10. Economic Geology

Several gold showings and one base metal occurrence have been identified in the Brownell Lake area. The first part of this section presents an overview of the history of gold exploration. This is followed by a summary of the character of the showings. This descriptive section concludes with a brief note about the base metal occurrence.

a) Gold

Most gold showings lie in the Brownell Lake Greenstone Belt, either within the periphery of the Brownell Lake Pluton or in supracrustal rocks to the west of this intrusion. Figure 3 illustrates the distribution of these showings; names for individual showings follow current terminology in use by Carina Resources, the owners of the group of claims.

History of Exploration at Brownell Lake:

The first documented work was during the period 1957–61 by the Knox Saskatchewan 1957 Syndicate (Assessment File 63L13-0003)[2]. This program included mapping, trenching, geophysical surveys and five diamond-drill holes. Only one of these, near the Dosco zone (Figure 3), intersected any significant gold values, the best of which was 1.2 m assaying 0.08 oz./ton. In 1965, United Comstock Lode Mines drilled one hole near the eastern side of the Emco trend (Assessment File 63L13-0007). No assay values are reported for this hole. In 1963, Selco included the Brownell Lake area in an airborne INPUT electromagnetic and magnetic survey that covered some 510 square miles (Assessment File 63L13-0006). Subsequent ground follow-up in 1965 included vertical coil EM and magnetometer surveys. Assessment work (Assessment Files 63L13-0008 and -0009) documented that, in 1967, at least four diamond-drill holes were completed including three in Brownell Lake and one northeast of the Olson showing. No assay values are reported.

In 1981, E.F. Partridge acquired MPP 1132, which included the previously identified showings at Brownell Lake. An intensive multi-faceted ground exploration program in 1982 focused on a strip in the mafic volcanics between Havard and Brownell Lakes, and defined six mineralized zones: the Abaco, Dosco, Emco, Olson, Siskin and Talco. Also during 1982, Partridge formed Carina Mineral Resources Corporation, which acquired mineral rights to MPP 1132. Additional prospecting and a Wacker Drill soil sampling program were completed in 1983. In 1984, 22 diamond-drill holes were completed on the Emco, Kaldo, Siskin, Sparton and Tuscan zones. Low-grade gold values over narrow intervals were intersected in most holes; the most encouraging results were from the linear Emco zone. An expanded prospecting program in 1985 resulted in the discovery of new showings, such as Jena, Juba, and Kalix which are associated with the periphery of the Brownell Lake pluton.

More recently, an agreement was reached between Carina Mineral Resources and Waddy Lake Resources Inc. whereby Waddy can earn up to a 50 percent interest in the property by completing certain exploration expenditures. As part of the agreement, Waddy had the permit area flown by Questor Surveys, undertook additional ground follow-up, and in 1987 completed 11 holes which tested for gold mineralization at the Emco, Jena, Kalix and Talco zones, as well as the granodiorite-hosted Alex zone on Maynard Lake and a geophysical anomaly 4 km south of the western end of Maynard Lake. This work defined a westward extension to the Emco mineralized zone, which lies in a quartz vein at the fault contact between fine-grained amphibolite in the footwall and staurolite schist in the hanging wall. The best intersection was 1.49 m grading 0.114 oz./t Au. Drill tests of the Talco, Abaco, Kalix and Jena showings were not encouraging. Waddy undertook additional ground follow-up during 1988, the results of which have not yet been reported.

Current Synthesis:

The geological context of some of the showings is still unclear whereas for others relationships are better understood. The following synthesis is based on observations of the author supplemented by discussions with industry personnel. Also presented are geochemical analytical data for a small suite of samples from the showings (Tables 1 and 2). These data were obtained as the first phase of an investigation of element associations in the Brownell gold showings.

Most showings in the Brownell Lake Pluton (i.e., Jena and Kalix; Figure 3) are characterized by a localized irregular network of narrow quartz veins that lie within a few metres or tens of metres of the periphery of this intrusion. In some cases, more that one generation of quartz veins are present. Patchy concentrations of arsenopyrite, pyrite and minor chalcopyrite are present in some but not all generations of quartz veins. Mineralized quartz veins are enriched in Ag, As, Cu and Zn (Tables 1 and 2). Patchy grades, together with the small irregular nature of these showings would not be expected to favor the hosting of significant mineralization.

Point Showing: One showing in the margin of the Brownell Lake Pluton, the Point, is different from the others, as it is hosted in an approximately 2 m wide shear zone in the porphyritic granodiorite. Within this tectonized zone are several sheared arsenopyrite-bearing quartz veins. Two arsenopyrite-bearing grab samples from these veins contained insignificant gold (Table 1) and the shear zone does not appear to have much strike continuity.

Emco Showing: Of the showings in volcanic rocks of the Brownell Lake Group, the most significant is the Emco, which is characterized by an arsenopyrite-bearing quartz vein, as well as sheared siliceous rocks at the fault contact between staurolite schist in the hanging wall and foliated mafic volcanics with disseminated arsenopyrite and small veinlets in the footwall. The east-trending fault zone which hosts this mineralization has a strike length of several kilometres; the slice of staurolite schist has been traced along the eastern end of the fault for 3 km. So far, only the eastern kilometre of the structure has been drilled and only to shallow depths. The best intersections, which come from a small fan of holes collared on the east shore of Lake 30, included hole 87-3 which intersected 0.104 oz./t Au over 1.68 m and hole 87-11 which intersected 1.49 m of 0.114 oz./t Au. The mineralization is open both to the west and at depth.

Siskin Showings: At other showings in the volcanics of the Brownell Lake Group, the character of the gold mineralization is apparently more complex and diverse.

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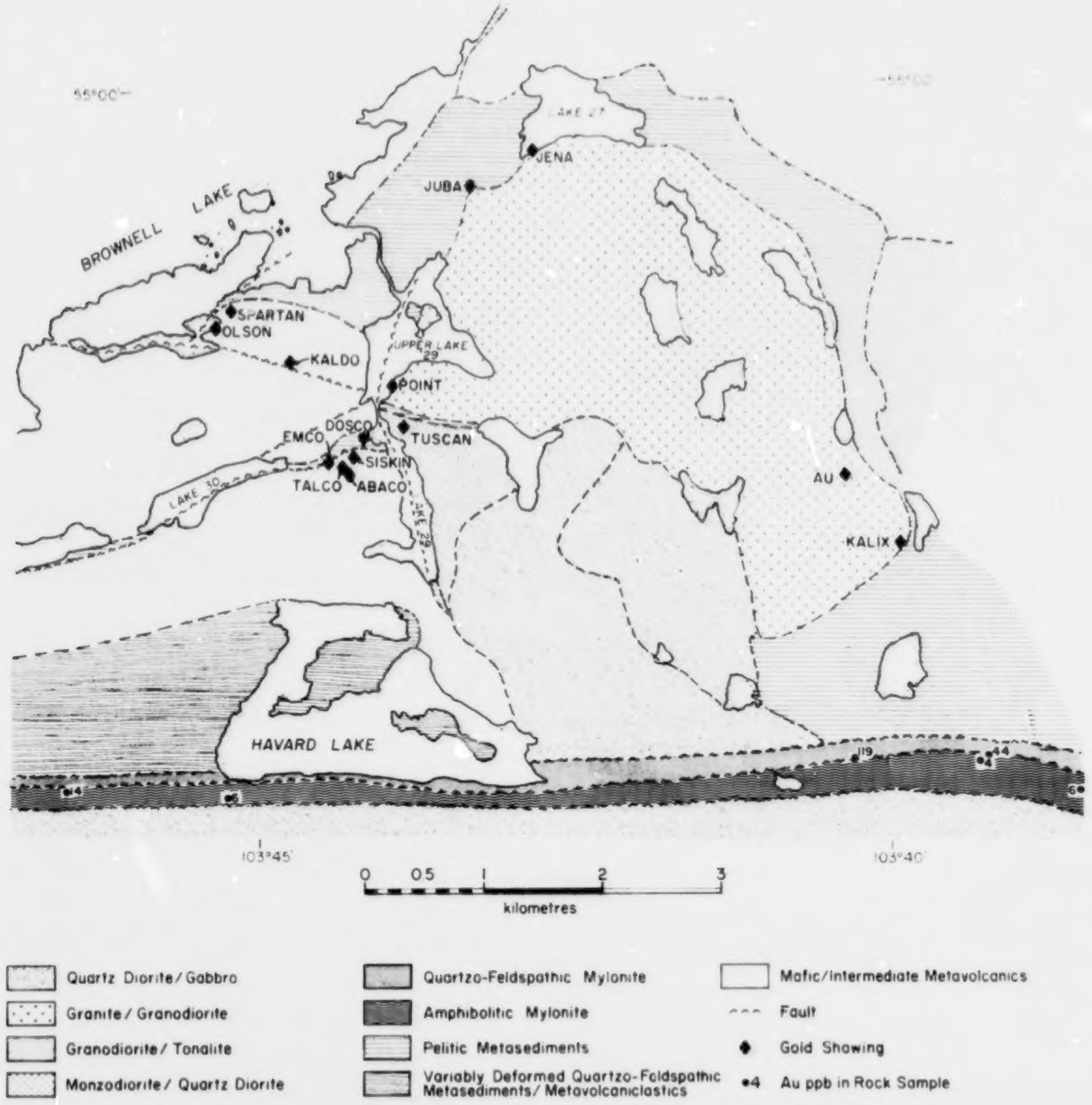
(2) Saskatchewan Energy and Mines, Regina

At the Siskin showing, anomalous concentrations of gold are found:

1) in strongly foliated amphibolite cut by chalky millimetre-thick veinlets and two intersecting fracture systems. The veinlets are composed of quartz, hornblende, calcite and chalcopyrite. Flecks of arsenopyrite form coatings on both fracture surfaces. A composite grab sample (8822-387, Table 1) contained insignificant concentrations of gold.

2) in pillowed intermediate volcanics cut by veinlets similar to those described in (1) and also hosting an irregular network of yellowish buff quartz, calcite, arsenopyrite and chalcopyrite veins. These veins pinch and swell in thickness, reaching a maximum of about 10 cm. Analysis of a grab sample (8822-388, Table 1) of these veins, which are characterized by clotted concentrations of arsenopyrite, revealed not only their significant enrichment in arsenic but also high contents of gold and silver, as well as slightly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Granodiorite/Tonalite
Monzodiorite/Quartz Diorite
Quartzo-Feldspathic Mylonite
Amphibolitic Mylonite
Pelitic Metasediments
Variably Deformed Quartzo-Feldspathic Metasediments/Metavolcaniclastics
Mafic/Intermediate Metavolcanics
Fault
Gold Showing
•4 Au ppb in Rock Sample

Figure 3 - Gold showings, Brownell Lake area and gold content in selected rock samples from the Hartley Shear Zone. Gold contents in the Hartley Shear Zone are for the following sample numbers, listed from left to right as they appear on the figure: 8822-3088, -338, -1114, -143, -142 and -1133. Additional analytical data for these samples are presented in Table 2.

elevated concentrations of cobalt and nickel.

3) in a narrow ferrigenous shear zone that cuts foliated amphibolite.

b) Base Metals

In 1958, a copper-zinc occurrence was discovered by INCO approximately 2 km east of Brownell Lake. Scott (1981) presented a history of exploration and description of this showing, known as the Brownell Lake property. As no further work has been done since his report this information will not be repeated here.

c) Synthesis and Recommendations for Future Gold Prospecting

All known gold showings in the Brownell Lake Greenstone Belt occur within the marginal zone of, or are peripheral to, the Brownell Lake Pluton. Showings within the marginal zone are hosted in quartz veins that form either an irregular network or occur within narrow discontinuous shear zones.

Although most showings outside the pluton lie within mafic to intermediate volcanics of the Brownell Lake Group (Figure 3), two are found in other rock types close to the contact of the pluton. Some of the showings in the metavolcanics appear to be hosted in patchy, multiphased, narrow vein systems. Most require further investigation for a better understanding of their context.

From work completed to date, the most favourable setting for a significant deposit is in mineralized quartz veins emplaced in the east-trending fault that juxtaposes staurolite schist and amphibolite. From the orientation and character of this fault, it is interpreted as a small thrust fault related to the Hartley Shear Zone. A careful reanalysis of structural style of the Brownell Lake Greenstone Belt might serve to identify other east-trending fault zones favourable for hosting gold mineralization.

A small group of grab samples of mylonite from the Hartley Shear Zone was analyzed for gold as well as other elements (Table 2; Figure 3). Two of these samples, 8822-142 and -1114, contained significantly

Table 1 – Sixteen-Element ICP-MS Assay for Selected Mineralized Samples from Gold Showings in the Brownell Lake Area. Analyses by Acme Laboratories, Vancouver

		Sample No. (8822-)							
		8	*96*	*136*	*137*	*218*	*387*	*388*	*1291*
Mo	(%)	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001
Cu	(%)	0.01	0.04	0.01	0.01	0.01	0.01	0.01	0.03
Pb	(%)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Zn	(%)	0.01	0.01	0.01	0.01	0.03	0.01	0.01	0.01
Ag	(oz./ton)	0.02	0.02	0.01	0.03	0.07	0.01	0.44	0.05
Ni	(%)	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Co	(%)	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Mn	(%)	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.01
Fe	(%)	2.40	6.39	2.62	3.57	3.09	0.94	15.14	9.21
As	(%)	1.19	7.39	1.40	2.35	3.08	0.02	20.76	10.13
U	(%)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Th	(%)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cd	(%)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Sb	(%)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Bi	(%)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Au	(oz./ton)	.016	.013	.009	.007	.815	.002	.317	.022

Sample Descriptions:

Sample No.	UTM Co-ordinates	Showing	Rock Type
8822-8	6092270N; 581280E	Unnamed	Quartz veinlets containing arsenopyrite, chalcopyrite and pyrite
8822-96	6093300N; 579710E	Olson	En-echelon arsenopyrite-bearing quartz veins in amphibolite
8822-136	6092840N; 581240E	Point	Arsenopyrite-bearing quartz vein in shear zone
8822-137	6092840N; 581240E	Point	Arsenopyrite-bearing sheared quartz vein
8822-218	6091500N; 585460E	Kalix	Arsenopyrite-bearing quartz vein cutting porphyritic granite
8822-387	6092190N; 580880E	Siskin	Chalcopyrite and arsenopyrite in quartz, calcite and hornblende veinlets
8822-388	6092190N; 580860E	Siskin	Arsenopyrite clots in quartz and calcite veinlets cutting pillowed andesite
8822-1291	6094780N; 582390E	Emco	Arsenopyrite vein in amphibolite

Table 2 – Thirty-Element Semiquantative ICP Analyses Plus AA Analysis for Gold for Selected Rock Samples from the Brownell Lake Area. Analyses by Acme Laboratories, Vancouver

		Sample No. (8822-)										
		20	*142*	*143*	*200*	*243*	*338*	*399*	*1019*	*1114*	*1133*	*3088*
Mo	(ppm)	1	1	1	1	2	1	1	15	1	1	1
Cu	(ppm)	113	155	70	12	3	38	7396	219	350	183	61
Pb	(ppm)	2	4	4	2	2	2	42	8	5	2	2
Zn	(ppm)	10	96	63	19	3	51	181	392	84	91	32
Ag	(ppm)	.1	.1	.1	.1	.1	.2	50.3	.7	1.5	.2	.2
Ni	(ppm)	86	3	3	130	2	9	1	69	3	4	16
Co	(ppm)	34	5	11	10	1	11	4	15	5	9	14
Mn	(ppm)	125	906	518	269	47	278	298	389	1029	868	256
Fe	(%)	3.94	4.46	4.1	2.49	.39	3.94	6.97	4.49	4.2	5.05	4.42
As	(ppm)	1210	4	3	5	298	4	118	79	10	2	2
U	(ppm)	5	5	5	5	5	5	5	10	5	5	5
Au	(ppm)	0	0	0	0	0	0	6	0	0	0	0
Th	(ppm)	1	2	1	1	1	1	1	6	2	2	1
Sr	(ppm)	16	16	10	1	3	28	3	3	55	12	22
Cd	(ppm)	1	1	1	1	1	1	1	1	1	1	1
Sb	(ppm)	2	2	2	2	2	2	2	2	2	2	2
Bi	(ppm)	2	2	2	2	2	2	75	2	2	2	2
V	(ppm)	22	31	45	15	2	35	20	232	21	80	62
Ca	(%)	2.83	.97	.89	.03	.04	1.3	.02	.15	1.67	.86	1.24
P	(%)	.022	.069	.105	.002	.005	.2	.021	.05	.069	.142	.149
La	(ppm)	2	16	14	2	3	12	4	19	17	15	9
Cr	(ppm)	11	1	1	510	4	13	3	70	3	2	9
Mg	(%)	.12	.6	.84	1.12	.04	.93	.34	1.24	.48	.92	.85
Ba	(ppm)	14	175	384	19	6	164	50	39	104	310	35
Ti	(%)	.08	.3	.18	.01	.01	.08	.09	.26	.14	.27	.05
B	(ppm)	4	5	2	5	2	6	2	2	3	7	6
Al	(%)	1.02	1.89	1.64	.07	.05	1.22	1.16	1.75	1.52	1.96	1.16
Na	(%)	.04	.03	.05	.01	.01	.07	.01	.02	.04	.04	.07
K	(%)	.01	1.08	.67	.01	.03	.24	.48	1.01	.55	1.14	.07
W	(ppm)	1	1	1	1	1	1	1	1	1	1	1
Au	(ppb)	13	44	4	2	132	6	10215	10	119	6	14

Sample Descriptions:

Sample No.	UTM Co-ordinates	Rock Name
8822-20	6093500N; 581315E	Sulphidic schist
8822-142	6089690N; 586200E	Quartz-feldspar mylonite
8822-143	6089650N; 586150E	Quartz feldspar mylonite
8822-200	6096330N; 587740E	Ferrigenous calc-silicate schist
8822-243	6094790N; 582390E	Quartz vein JENA showing
8822-338	6089370N; 579830E	Amphibolitic mylonite
8822-399	6097550N; 565670E	Gossan ALEX showing
8822-1019	6094790N; 582390E	Sulphidic schist JENA showing
8822-1114	6089790N; 585080E	Quartz feldspar mylonite
8822-1133	6089450N; 587050E	Amphibolitic mylonite
8822-3088	6089390N; 578450E	Amphibolitic mylonite

anomalous gold concentrations of 44 and 119 ppb respectively. Obviously, this part of the Hartley Shear Zone and its strike continuity require thorough investigation. Similarly, the northern sheared margin of the Brownell Lake Greenstone Belt should be evaluated for its gold potential. On a broader scale, a careful reanalysis of existing mapping coupled with airphoto analysis might serve to identify other major shear zones in the southern Glennie Lake Domain.

11. Acknowledgements

I wish to thank Bob McLennan and Jim Zimmerman of Carina Resources for invaluable information on the gold showings, as well as permission to use the Carina campsite on Brownell Lake. Linda Lewis of Orequest Resources, working on behalf Waddy Lake Resources, provided additional insight into the gold showings. John Lewry and Larry Craig are thanked for stimulating discus-

sions and revealing observations of geological relationships.

12. References

Chiarenzelli, J.R., Lewry, J.F. and Landon, M. (1987): Bedrock geology, Iskwatikan Lake area: evidence for Hudsonian juxtaposition of Proterozoic and Archean rocks along a ductile detachment surface; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p46-51.

Coombe, W. (1984): Gold in Saskatchewan; Sask. Energy Mines, Open File Rep. 84-1, 134p.

DeLury, J.S. (1926): Wapawekka and Deschambault Lakes area, Saskatchewan; Geol. Surv. Can., Summ. Rep. 1924, Pt. B. p23B-50B.

Hornbrook, E.H.W., Garrett, R.G., Lynch, J.J. and Beck, L.S. (1975): Regional lake sediment reconnaissance data, east-central Saskatchewan; Geol. Surv. Can., Open File 266, 108p.

________ (1977): Regional lake sediment reconnaissance data, east-central Saskatchewan; Geol. Surv. Can., Open File 488.

Hornbrook, E.H.W., Lynch, J.J., Friske, P.W.B., Lund, N.D., and Schmitt, H.R. (1985): Regional lake sediment reconnaissance data, east-central Saskatchewan; Geol. Surv. Can., Open File 1129, 145p (8 maps).

Lewry, J.F. (1981): Lower Proterozoic arc-microcontinent collisional tectonics in the western Churchill Province; Nature, v294, no5836, p69-72.

Lewry, J.F., Sibbald, T.I.I. and Rees, C.J. (1978): Metamorphic patterns and their relation to tectonism and plutonism in the Churchill Province; *in* Fraser, J.A. and Heywood, W.W. (eds), Metamorphism in the Canadian Shield; Geol. Surv. Can., Pap. 78-10, p139-153.

Lewry, J.F., Thomas, D.J., Macdonald, R. and Chiarenzelli, J. (1987): Structural relations in accreted terranes of the Trans-Hudson Orogen, Saskatchewan: telescoping in a collisional regime (abstract); Geol. Assoc. Can./Mineral. Assoc. Can., Joint Annu. Meet., Saskatoon, May 1987, Prog. Abstr., v12, p67.

Macdonald, R. (1981): Compilation bedrock geology: Pelican Narrows and Amisk Lake areas; 1:250,000 scale prelim. map *with* Summary of Investigations 1981, Sask. Geol, Surv., Misc. Rep. 81-4.

Macdonald, R. (1987): Update on the Precambrian geology and domainal classification of northern Saskatchewan; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87.4, p87-104.

McInnes, W. (1913): The basins of the Nelson and Churchill River; Geol. Surv. Can., Mem. 30.

Padgham, W.A. (1968): The geology of the Deschambault Lake district comprising the Oskikebuk Lake area, Viney Lake area (west half), the northern part of the Ballantyne Bay area, and the northeast quarter of the Limestone Lake area, Saskatchewan (63-L-13, 63-L-14-W and parts of 63-L-11, 12); Sask. Dep. Miner. Resour., Rep. 114, 92p.

Scott, B.P. (1981): Geology of the Maynard Lake - Sandy Narrows (west) area (NTS area 63M-4 and 63M-3W); Sask. Miner. Resour., Rep. 186, 26p.

Streckeisen, A. (1976): To each plutonic rock its proper name; Earth Sci. Rev., v12, p1-33.

Taylor, F.C. (1958): Pelican Narrows, Saskatchewan; Geol. Surv. Can., Map 1-1958 (with descr. notes).

Van Schmus, W.R. and Bickford, M.E. (1984): Preliminary U-Pb age data for the Trans-Hudson Orogen in northern Saskatchewan; *in* Summary of Investigations 1984, Sask. Geol. Surv., Misc. Rep. 84-4, p81-85.

Project 8812

Bedrock Geological Mapping, Palf Lake Area (Part of NTS 63M-3 and -4 and 63L-13 and -14)[1]

D.J. Thomas

Thomas, D.J. (1988): Bedrock geological mapping, Palf Lake area (part of NTS 63M-3 and -4 and 63L-13 and -14); *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

This summer, revisional geological mapping at 1:20,000 scale of 320 km^2 was conducted in the general Palf Lake area. The centre of the area lies approximately 45 km southwest of Pelican Narrows and is situated in portions of NTS 63M-3 and -4 and 63L-13 and -14. The area is easily accessible by float-equipped aircraft from Pelican Narrows, La Ronge and Flin Flon.

The Palf Lake area forms the central part of a north-south transect, mapped this summer, extending from Gee Lake (Slimmon, this volume) to Brownell Lake (Delaney, this volume) in the southern part of the Glennie Domain. The purpose of this mapping transect was to provide a better understanding of the apparent structural and metamorphic variations across the southern portion of the domain, as well as providing a more detailed examination of the various supracrustal belts and intrusive rocks, particularly with respect to their economic potential.

The geology of the Palf Lake area was included in an early compilation of NTS 63M by Taylor (1958), and in a more recent compilation of 63M and 63L by Macdonald (1981). This summer's mapping included portions of areas previously mapped at 1:63,360 scale by Padgham (1966 ,1968) and Scott (1981).

The area is also covered by the following geophysical maps: 1) 1:63,360 scale Federal-Provincial aeromagnetic series maps 4593G (Oskikebuk Lake, 63L-13), 4584G (Sandy Narrows, 63M-3), 4594G (Viney Lake, 63L-14) and 4822G (Maynard Lake, 63M-4); 2) 1:250,000 scale Federal-Provincial aeromagnetic series maps 7754G (Amisk Lake, 63L) and 7764G (Pelican Narrows, 63M).

1. Regional Geology

The Palf Lake area lies within the southern portion of the Glennie Domain which forms one part of the larger Reindeer Zone of the Trans-Hudson Orogen (Stauffer, 1984; Lewry et al., 1985; Lewry et al., 1987). The Reindeer Zone represents a collage of Early Proterozoic volcanic arc and related plutonic rocks, associated volcanogenic clastic assemblages, and younger meta-arkosic molasse. The Glennie Domain is characterized by narrow arcuate supracrustal belts of metavolcanic and metasedimentary rocks within a predominantly granitoid terrane of early foliated quartz dioritic to granitic gneisses, younger plutons and their tectonized equivalents. More recent work has established the presence of Archean basement inliers separated from allochthonous Proterozoic thrust sheets by major promylonitic to mylonitic shear zones (Lewry et al., 1987).

2. General Geology of the Palf Lake Area

A northwest-trending supracrustal belt, varying from 3.0 to 5.5 km in width, extends for about 30 km through the Palf Lake area (Figure 1). The belt has been intruded to the northeast by a large plutonic complex comprising pre- to late syntectonic diorite, quartz diorite, granodiorite and granite phases, here termed the *Lueder Lake Batholith*, which includes the previously named Lueder Lake Granite and Arn Lake Granite bodies (Macdonald, 1981). The supracrustals are bounded to the southwest by foliated granodioritic to granitic rocks of the *Carroll Lake Granite Gneiss* (Macdonald, 1981) and the *Hidden Bay pluton* (Padgham, 1968). Southeast of Kvamsing Lake, the Palf Lake belt merges with the east-trending Brownell Lake belt. The Palf Lake belt branches into several narrow belts which wrap around and occupy embayments within a tonalitic-granodioritic body east of Palf Lake. Several narrow belts (less than 0.5 km wide) of variably migmatized and locally highly strained supracrustal rocks occur as discontinuous enclaves or septa within the intrusions. Numerous pre- to syntectonic sill-like intrusions, ranging in composition from granite through granodiorite to dioritic gabbro, have been emplaced within the supracrustal succession. Posttectonic intrusive rocks are not prevalent in the area.

The Palf Lake area has undergone four major tectonic events (D_1 to D_4) which have produced complex fold interference patterns and high-strain shear zones. Middle to upper amphibolite facies conditions were maintained throughout D_1 to D_3 events but locally decreased to upper greenschist facies during the D_4 event.

3. Supracrustal Rocks of the Palf Lake Belt

Metavolcanic rocks, comprising approximately 70 percent of the supracrustal lithologies in the Palf Lake belt, predominate to the north, while metasedimentary rocks increase proportionately to the southeast, particularly

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(1) Project funded under the Saskatchewan component of the Canada - Saskatchewan Subsidiary Agreement on Mineral Development 1984 - 89

around Palf Lake itself. Due to the strong deformation in the area, reliable top indicators have not been preserved sufficiently well to resolve the stratigraphic younging direction of the metavolcanic-sedimentary succession.

a) Metavolcanic Rocks

The Palf Lake belt is dominated by mafic to intermediate metavolcanic rock types, while felsic metavolcanic varieties comprise less than 5 percent of the supracrustal succession. Mafic varieties have greater than 35 percent amphibole and negligible visible quartz. Mafic metavolcanics vary from hornblende-plagioclase gneiss/schist to amphibolitic rocks. Intermediate metavolcanic rocks with 15 to 35 percent mafics (e.g., biotite, chlorite, amphibole, garnet) contain minor visible quartz. Mafic and intermediate metavolcanic rocks occur interlayered in approximately equal amounts throughout the supracrustal sequence, although at outcrop scale one compositional variety typically predominates. Minor pelitic, psammopelitic and psammitic schists tend to be spatially associated with the more intermediate to felsic metavolcanic portions of the sequence, and can be difficult to distinguish from the volcanics. Amygdaloidal, lapilli to tuff breccia and feldspar-phyric textures are locally preserved within the metavolcanic rocks.

Identifiable depositional sequences of volcanic assemblages are locally recognized in the supracrustal succession. For example, a 1 km wide belt of predominantly amygdalodial feldspar-phyric mafic metaflows with minor fine-grained metatuffs extends for about 3.5 km southeast of Jacques Lake. To the southwest, and structurally underlying this composite flow package is a narrow (less than 100 m wide) interval of mafic to intermediate lapilli metatuffs and metatuff breccias with minor felsic rocks of uncertain origin. There is a general lack of recognizable volcaniclastic features throughout much of the Palf Lake area except for very local occurrences. The absence of volcaniclastic rocks may only be apparent in that fragmental fabrics, if present, may have been obliterated during the intense deformation and metamorphic recrystallization which has affected the area. Alternatively, the general paucity of tuffaceous assemblages could indicate a volcanic regime predominantly characterized by massive composite flows (e.g., submarine rift volcanism?).

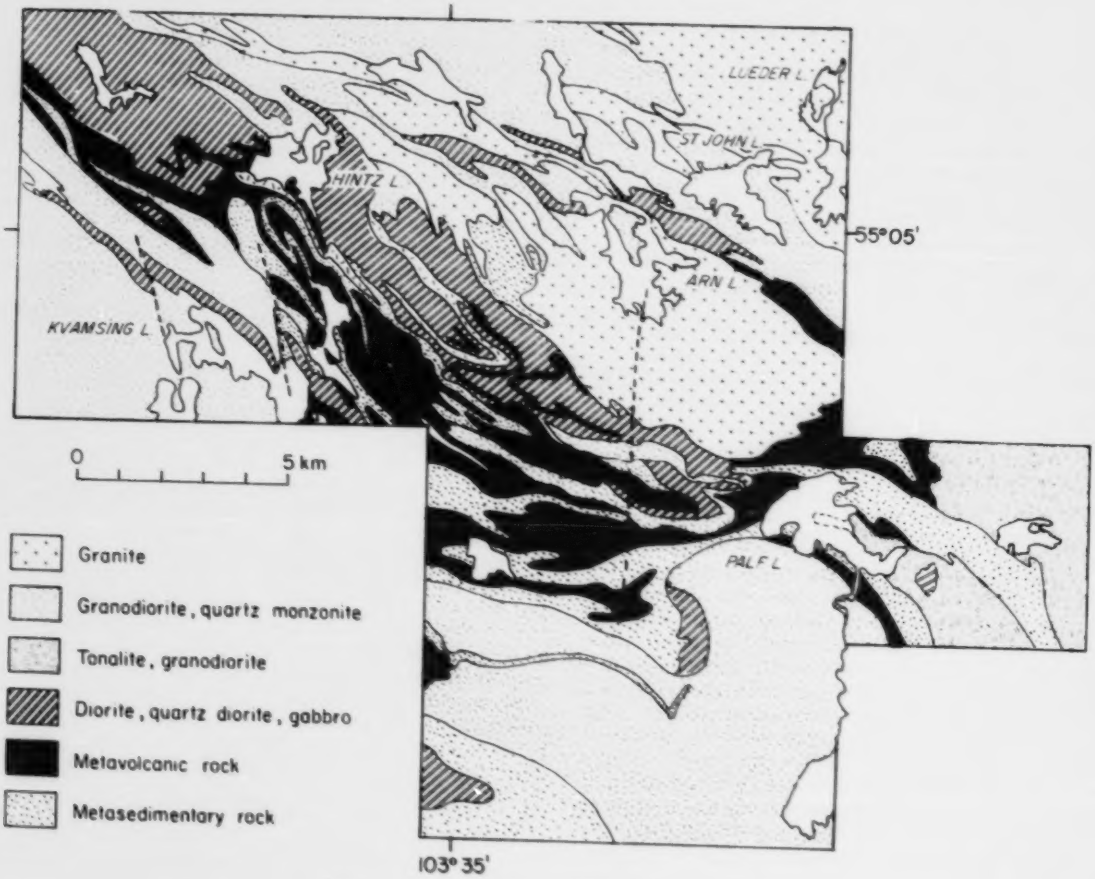

Figure 1 - General geology of the Palf Lake area.

b) Metasedimentary Rocks

Metasedimentary assemblages become more prevalent in the southeastern part of the belt. Metasediments between Kvamsing and Palf Lakes are predominantly pelites and psammopelites, with lesser psammites and amphibolitic pelites. Subidioblastic to idioblastic garnet, 0.2 to 2.0 mm in diameter, constitutes up to 15 percent of these rocks. Quartzofeldspathic segregations are locally developed in the more pelitic and psammopelitic varieties.

Light grey to pinkish grey, fine- to medium-grained rocks varying from quartzitic psammites to meta-arkoses occur at narrow (less than 10 m wide) intervals throughout the sequence. A pale pinkish white, fine-grained felsic rock containing small (0.25 to 1.0 mm diameter) pale blue quartz grains occurs as several narrow (less than 10 m wide) intervals between the south ends of Kvamsing and Jacques Lakes. Whether these rocks represent a quartz-phyric felsic volcanic (e.g., rhyolite) or a quartz granule meta-arkosic grit remains unresolved. A narrow arkosic metaconglomerate layer, 5 to 10 m wide, occurs 1 km northwest of Palf Lake within a mixed sequence of intermediate metavolcanic schists and psammitic gneisses.

Calcareous Assemblages:

Metasedimentary assemblages are more calcareous in the southeastern part of the Palf Lake belt. Narrow horizons of calc-silicate gneiss and actinolite/tremolite-biotite schist (amphibolitic pelite) are increasingly interlayered with metavolcanic rocks to the southwest of Palf Lake along the north margin of the Hidden Bay pluton. These horizons appear to thicken eastwards, forming a major stratigraphic unit which extends through the central part of Palf Lake. Beginning at the structural base of this heterogeneous calcareous assemblage, the following lithologies are recognized: quartzitic psammites grading upwards into actinolite/tremolite-bearing calcareous psammites; overlain sharply by a variety of calc-silicate gneisses and schists which are increasingly interbedded upwards with amphibolitic pelites and actinolite/tremolite-rich amphibolites; overlain sharply by medium to thickly bedded actinolite-garnet psammites and psammopelites.

Staurolite-Garnet-Bearing Assemblage:

Structurally overlying the calcareous assemblage at Palf Lake and extending east to Toro Lake is a 1 km wide assemblage of staurolite-garnet pelitic and psammopelitic gneisses with lesser amounts of variably garnetiferous psammitic and hornblende-plagioclase gneiss. The pelitic and psammopelitic gneisses are typically light grey to light olive grey, medium to coarse grained and contain 5 to 25 percent garnet, 0 to 5 percent reddish brown to brownish yellow staurolite and less than 10 percent biotite. Garnet and staurolite, which occur as a stable metamorphic paragenesis, form syntectonic xenoblastic to subidioblastic crystals that locally exceed 5.0 cm in length. Layering between garnet-rich and garnet-deficient rocks varies from very marked to gradational, with individual layers ranging from several tens of centimetres to several metres in thickness.

4. Intrusive Rocks

Intrusive rocks underlie approximately 60 percent of the Palf Lake area and can be grouped into four main bodies: the Lueder Lake Batholith, the Carroll Lake Granite Gneiss, the Hidden Bay pluton and the Toro Lake Tonalite. Numerous smaller sheet-like intrusive bodies occur throughout the supracrustal belt. All intrusive rocks have been affected to some degree by one or more of the major tectonic events. Unequivocally posttectonic intrusive rocks were not observed in the area.

a) Lueder Lake Batholith

The northeastern part of the area includes a small portion of the regionally extensive Lueder Lake Batholith. A geological compilation by Macdonald (1981) indicates that the rocks composing this intrusive complex probably underlie an area exceeding 350 km^2 and extend from Lovell Lake in the east to Sadler Lake in the west. The complex is heterogeneous and appears to have been emplaced over a considerable period of time, as indicated by the presence of "early" banded granodiorite-tonalite gneisses as well as "late" syntectonic porphyritic granites. Contact relationships between the various phases of the complex range from discrete and clearly crosscutting to gradational or diffuse.

The oldest rocks in the Palf Lake portion of the Lueder Lake Batholith are fine- to medium-grained, greyish white to medium grey granodiorite and tonalite gneisses. These "early" gneisses are not areally extensive, occur in a belt between Birkett and Hopper Lakes, and appear to form large blocks or remnants incorporated in younger phases of the complex. The rocks commonly possess a discontinuous streaky banding, ranging from 1 to 10 cm wide. The gneissic banding typically exhibits boudinage structure, intrafolial folds and refolded folds.

A suite of rocks of broadly dioritic composition represents the next major intrusive event of the Lueder Lake Batholith. The majority of the dioritic rocks occur along the southwestern margin of the body in contact with the supracrustal belt. Dioritic rocks, possibly related to the batholith, also occur as narrow sill-like bodies within the supracrustal belt, as well as narrow discontinuous bodies within the main part of the intrusive complex. The diorites are very heterogeneous and include the following lithologic varieties: medium- to coarse-grained mesocratic hornblende diorite, medium- to coarse-grained leucocratic quartz diorite, melanocratic garnetiferous diorite and dioritic gabbro, leucocratic to melanocratic gabbro, and fine- to medium-grained melanocratic homogeneous amphibolite. Primary rhythmic layering is locally preserved in gabbroic rocks southwest of Birkett Lake.

The fine- to medium-grained homogeneous amphibolites, particularly prevalent between Birkett and Hintz Lakes, are of uncertain origin. Previously mapped by

Scott (1981) as dominantly of volcanogenic origin, these rocks are rather monotonous over broad areas, lack significant mineralogical or textural differences and are largely devoid of any supracrustal features. The homogeneous amphibolites also display gradational contacts with unequivocal dioritic and layered gabbroic rocks which would suggest a plutonic origin. Previous mapping by Scott (1981) indicated a number of long narrow volcanic horizons throughout many of the dioritic bodies; however, most of these "supracrustal" intervals are reinterpreted as highly strained or sheared equivalents of the diorites.

Granodioritic, quartz monzonitic and granitic rock types form the main part of the Lueder Lake Batholith. Varieties include: 1) light grey to yellowish grey fine- to medium-grained hornblende-biotite granodiorite, 2) pale greyish pink to greyish white medium- to coarse-grained biotite-hornblende granodiorite, 3) medium- to coarse-grained light pink to medium pink hornblende-biotite quartz monzonite, and 4) pale pink to light red medium to coarse-grained biotite granite and quartz monzonite. Field relationships indicate that the granodiorite members are generally, though not universally, older than the granite. The quartz monzonitic rocks appear to be temporally transitional between the granodiorites and granites. All varieties possess penetrative foliations ranging from poorly to very well developed.

The youngest rocks recognized in the batholith, which occur northwest of St. John Lake and west of Lueder Lake, are fine- to coarse-grained, medium to light red aplogranite and feldspar porphyritic leucogranite. These rocks, which have been termed the Leuder Lake Granite (Macdonald, 1981), are generally very weakly foliated to locally massive.

b) Carroll Lake Gneiss

A small part of the much larger Carroll Lake Gneiss (Macdonald, 1981) occurs in the southwestern part of the area. This unit comprises a suite of weakly to very well foliated "granitic" rocks interpreted to be of largely plutonic origin. The main foliation is characterized by a penetrative planar fabric ranging from a very weak fracture cleavage to a strongly developed cataclastic schistosity rather than a ubiquitous gneissosity. Locally, a weak to faint gneissosity, defined by discontinuous bands of leucocratic quartzofeldspathic leucosome, predates the more prevalent but variably developed cleavage. Rocks along the southwest shore of Kvamsing Lake possess a well-developed, moderately to steeply southeast-plunging quartz rodding.

The oldest rock-type recognized in this part of the Carroll Lake Gneiss is a well-foliated, medium-grained, light greyish white hornblende-biotite tonalite discontinuously present along the southwest shoreline of Kvamsing Lake. The most common lithology is a light pink to medium red, equigranular, medium- to coarse-grained biotite granodiorite to quartz monzonite. The rocks commonly contain appreciable amounts of magnetite (up to 1 percent) and distinctive coarse-grained, reddish brown stained quartz aggregates. Syntectonic garnet, 0.25 to 1.0 mm in diameter, is locally present. The youngest phase recognized consists of 1 to 10 m wide sheets of pink to medium red, fine- to medium-grained biotite leucogranite and aplogranite. These rocks are particularly prevalent along the northeastern margin of the Carroll Lake Gneiss between Park and Kvamsing Lakes. Granitic intrusive sheets similar to the Carroll Lake Gneiss are prevalent in supracrustal and dioritic rocks northeast of Park and Kvamsing Lakes. These sheets, ranging from less than one metre to several hundred metres in width, appear to have been intruded as high-angle dykes but were transposed parallel to a major northwest-trending high-strain zone extending from Park Lake through the east side of Kvamsing Lake. There is a general absence of supracrustal material either as xenoliths along the margin or as larger enclaves in the Palf Lake part of the Carroll Lake Gneiss, somewhat in contrast to elsewhere in this unit (Scott, 1981).

c) Hidden Bay Pluton

The Hidden Bay pluton underlies approximately 40 km^2 south of Palf Lake and west of Hidden Bay on Deschambault Lake. The intrusion is compositionally and structurally similar to the Carroll Lake Granite Gneiss lying to the northwest and may form its southeastern extension. The predominant lithology is a pale pinkish grey to light pink, medium- to coarse-grained biotite granodiorite to quartz monzonite. Subordinate leucocratic fine- to medium-grained hornblende-biotite granodiorites are present in the eastern part of the intrusion. Aplogranite and coarser leucogranite varieties, similar to those described in the Carroll Lake Granite Gneiss, occur in the western part of the body. The pluton has a variable foliation ranging from a poorly developed preferred groundmass alignment to a well-developed cataclastic fabric. The rocks are progressively strained towards the northern margin of the pluton, where they are locally protomylonitic to mylonitic. In the northwestern lobe of the body, there is an intense steep northwest-plunging L-fabric defined by quartz rodding and lenticular biotite aggregates.

d) Toro Lake Tonalite

This summer's mapping included the western portion of a kidney-shaped body east of Palf Lake which was previously outlined by Padgham (1968) and Scott (1981). The body is composed of white to light grey, medium- to coarse-grained garnet-hornblende tonalite and granodiorite, collectively referred to here as the Toro Lake Tonalite. Coarse hornblende and local actinolite form up to 10 percent of the rock. Garnet, 0.25 mm to 1.0 cm diameter, normally constitutes 1 to 3 percent and locally up to 10 percent of the rock. Quartz ranges between 20 and 40 percent. A coarse crenulation foliation and steep north- to northwest-plunging quartz rodding fabric are pervasive throughout much of the body. Outcrops commonly display rough corrugated to spikey surfaces due to differential weathering of the crenulation foliation and rodded quartz grains. Weakly foliated aplogranite and leucogranite are present in minor amounts. The margin of the body is relatively free of xenoliths, except for garnetiferous metasediments which occur as long narrow bands toward the southwestern margin of the body. Garnetiferous pelitic and psammopelitic gneisses with minor mafic metavolcanics occupy a southeast-trending embayment (3 km long and 1 km wide) into the tonalitic-granodioritic gneisses to the southwest of Toro Lake. Numerous sheets of Toro Lake tonalite-granodiorite are interlayered with the supracrustal rocks in this embayment and locally are difficult to differentiate from the more quartzofeldspathic garnet-bearing metasediments.

5. Structural and Metamorphic History

The Palf Lake area has undergone polyphase deformation as evidenced by complex fold interference patterns and high-strain shear zones. The earliest penetrative fabric (S_1) in the supracrustal rocks is defined by a well-developed compositional banding or gneissosity ranging from millimetre through centimetre scale. This early gneissosity is generally parallel to subparallel to the gross compositional layering of the supracrustal rocks (S_0). The fine-scale gneissic banding or laminations rarely exceed strike lengths of several tens of centimetres to a metre, and wider bands (2 to 10 cm wide) typically pinch out within several metres. At an outcrop scale, gross compositional layering (S_0) can be traced for only a few tens of metres. This discontinuous banding and layering reflects the high degree of transposition of the original layering and early gneissosity. The gneissic foliation present in the oldest rocks of the Lueder Lake Batholith, and locally in the Carroll Lake Granite Gneiss, is probably of the same age as the S_1 gneissosity in the supracrustals.

The S_1 gneissosity is interpreted as a "bedding-parallel" foliation related to the development of tight to isoclinal and southwesterly recumbent first generation folds (D_1). The Carroll Lake Granite Gneiss and Palf Lake pluton, which occupy a major overturned antiform, may have been emplaced syntectonically during this D_1 event. The Palf Lake supracrustal belt has been folded around a major D_1 synformal axis.

The most pervasive fabric in the Palf Lake area is a northwest-trending, near-vertical to steeply northeast-dipping foliation (S_2). The foliation is variable in its intensity, ranging from a vague schistosity through well-developed continuous and spaced cleavages (Borradaile et al., 1982) to cataclastic and mylonitic fabrics. The S_2 foliation is axial planar to second-generation folds produced during an episode of heterogeneous simple-shear folding (D_2). The resultant D_1/D_2 refolded structures are difficult to detect in large-scale features, but their presence is supported by Type 3 (Ramsay, 1967) minor folds that are best developed in the supracrustal rocks. During the D_2 event, major northwest-trending high-strain zones are believed to have developed throughout the supracrustal sequence and to a lesser degree in the intrusive rocks. One regional-scale high-strain zone extends from Park Lake through Kvamsing Lake and follows the contact between the Carroll Lake Granite Gneiss and a diorite-gabbro body. South of Kvamsing Lake, this deformation zone swings more easterly, following the contact between the supracrustal rocks and the Hidden Bay pluton. A down-dip stretching lineation, defined by quartz rodding in granitoid rocks and by mafic mineral aggregates in mafic lithologies, is more pronounced towards the footwall of the zone. Immediately southeast of Kvamsing Lake, the lineation is stronger than the foliation, producing a moderately plunging southeast L-tectonite fabric. Similarly, a moderately to steeply plunging northwest L-tectonite fabric is developed in the northwesternmost lobe of the Hidden Bay pluton and in the adjacent supracrustals. The majority of intrusive rocks have been affected to varying degrees by the D_2 event.

A subvertical north- to northeast-trending cleavage (S_3) is best developed in the southeastern part of the area. The foliation deforms the earlier S_2 cleavage, resulting in a locally developed crenulation fabric with a steep north-plunging intersection lineation. The S_3 foliation is axial planar to a late set of north- to northeast-trending upright cross-folds (D_3), producing a Type 1 "dome-and-basin" interference pattern incorporating the earlier D_1/D_2 structures. The plunge reversal of D_2 linear fabrics southeast of Kvamsing Lake is probably the result of folding around a northeast-trending D_3 synformal axis. The majority of the aplogranites and leucogranites appear to have been emplaced towards the end of the D_3 event.

North-trending brittle faults, some with an apparent sinistral sense of displacement, mark the last deformation (D_4) to affect the area.

The relationship between metamorphic mineral assemblages and kinematic fabrics indicates that middle to locally upper amphibolite facies conditions were achieved during the first thermotectonic event (D_1/M_1) and were maintained through the second and third episodes (D_2/M_2, D_3/M_3). Retrogression to greenschist facies mineral assemblages (muscovite-chlorite subfacies) occurred locally as a result of the D_4 faulting event.

6. Economic Geology

A limited amount of prospecting activity appears to have been conducted in the Palf Lake area according to the Saskatchewan Energy and Mines assessment files. Several regional-scale airborne geophysical surveys, including electromagnetic, magnetic and radiometric spectrometry, were conducted over portions of the area in the late sixties, but follow-up ground investigations were minimal. A number of mineral dispositions presently cover the area southeast of Kvamsing Lake, south of Palf Lake to Deschambault Lake, southeast of Arn Lake and southwest of Birkett Lake.

Minor amounts of disseminated magnetite, pyrite and pyrrhotite occur throughout the metavolcanic-metasedimentary sequence. A series of small gossans containing pyrite, pyrrhotite and traces of arsenopyrite occur at the southeast end of a small lake about 500 m north of Kvamsing Lake (UTM grid reference 13UEM873040). Another highly magnetic gossan of basic granulite (possibly metagabbro or calc-silicate), containing 10 to 20 percent coarse pyrite and pyrrhotite, occurs 3.5 km southwest of Palf Lake (UTM grid reference 13UEL963946). Trace amounts of chalcopyrite occur in calc-silicate gneiss at Palf Lake. Sheared diorites northwest of Hintz Lake commonly contain several percent finely disseminated magnetite.

a) Suggestions to Prospectors Concerning Gold

The Palf Lake area has been evaluated at only a cursory level in the past with respect to its gold potential. Many of the characteristics common to gold mineralization in other greenstone belts are also present, to varying degrees, in the Palf Lake area. These include regional-scale high-strain zones, composite ductile-brittle and ductile shear systems, and the presence of felsic intrusions. A thorough examination of the northwest-trending shears between Jacques and Hintz Lakes, as well as the major high-strain zone extending through Park, Kvamsing and Palf Lakes, is warranted. Geophysical methods have had limited success in delineating mineralized shear structures in the Star Lake gold camp; therefore, the importance of careful geological bedrock mapping when prospecting for shear-controlled gold mineralization in the Palf Lake area must not be underrated.

7. References

Borradaile, G.L., Bayly, M.B. and Powell, C. McA. (1982): Atlas of Deformational and Metamorphic Rock Fabrics; Springer-Verlag, 551p.

Lewry, J.F., Sibbald, T.I.I. and Schledewitz, D.C.P. (1985): Variation in character of Archean rocks in the western Churchill Province and its significance; *in* Ayres, L.D., Thurston, P.C., Card, K.D. and Weber, W. (eds.), Evolution of Archean Supracrustal Sequences; Geol. Assoc. Can., Spec. Pap. 28, p239-261.

Lewry, J.F., Thomas, D.J., Macdonald, R., and Chiarenzelli, J. (1987): Structural relations in accreted terranes of the Trans-Hudson Orogen, Saskatchewan: telescoping in a collisional regime (abstract); Geol. Assoc. Can./Mineral. Assoc. Can., Joint Annu. Meet., Saskatoon, May 1987, Prog. Abstr., v12, p67.

Macdonald, R. (1981): Compilation bedrock mapping: Pelican Narrows and Amisk Lake areas; 1:250,000 scale prelim. map *with* Summary of Investigations 1981, Sask. Geol. Surv., Misc. Rep. 81-4, p16-23.

Padgham, W.A. (1966): The geology of the Wapawekka Narrows area (north half); Sask. Dep. Miner. Resour., Rep. 87, 113p.

________ (1968): The geology of the Deschambault Lake district comprising the Oskikebuk Lake area, Viney Lake area (west half), the northern part of the Ballantyne Bay area and the northeast quarter of the Limestone Lake area; Sask. Dep. Miner. Resour., Rep. 114, 92p.

Ramsay, J.G. (1967): Folding and Fracturing in Rocks; McGraw Hill, 568p.

Scott, B.P. (1981): Geology of the Maynard Lake - Sandy Narrows (west) area; Sask. Miner. Resour., Rep. 186, 26p.

Stauffer, M.R. (1984): Manikewan: an Early Proterozoic ocean in central Canada, its igneous history and ocean closure; Precambrian Res., v25, p257-281.

Taylor, F.C. (1958): Pelican Narrows, Saskatchewan: Geol. Surv. Can., Map 1-1958 (1:63,360 scale map with marginal notes).

Project 8830

Bedrock Geological Mapping, Gee Lake Area (Part of NTS 63M-3 and -4)[1]

W.L. Slimmon

Slimmon, W.L. (1988): Bedrock geological mapping, Gee Lake area (part of NTS 63M-3 and -4); *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

The Gee Lake area, located approximately 35 km west of Pelican Narrows, comprises a 200 km^2 region which was geologically remapped this summer at a scale of 1:20,000 (Figure 1). This is the northern component of three contiguous map areas in a north-south transect across part of the Glennie Domain which is part of the Trans-Hudson Orogen. The projects were undertaken to gain a better understanding of the geological context of supracrustal belts in the domain and to characterize metallic mineral deposits, particularly gold mineralization, associated with the belts.

Surface topography consists of numerous small interconnected lakes interspersed between gently rolling hills with a maximum relief of 150 m. Precambrian bedrock is obscured beneath a thin veneer of Quaternary glacial morainal deposits over most of the area and by glaciolacustrine deposits in the immediate vicinity and to the north of Gee Lake (Schreiner, 1984). Up to 50 percent of the bedrock is exposed in areas underlain by granitoid rock; however, exposure decreases to about 20 percent in supracrustal regions.

The area was previously mapped in the mid-seventies at 1:63,360 scale by Scott (1981). Compilation maps encompassing the area include a 1:253,440 scale map of the Pelican Narrows area (Taylor, 1958) and a preliminary 1:250,000 scale compilation of the Pelican Narrows-Amisk Lake area (Macdonald, 1981). Geological Survey of Canada aeromagnetic maps that cover the area include a 1:250,000 scale map 7764G (63M) and 1:63,360 scale maps 4584G (63M-3) and 4822G (63M-4). The area is also included in a regional lake sediment geochemical survey completed in 1974 by the Geological Survey of Canada (Hornbrook et al., 1975, 1977, 1985).

1. Regional Geology

The Gee Lake study area is located in the central part of the Glennie Domain, which forms part of the Reindeer Zone of the Trans-Hudson Orogen. The Glennie Domain has been regarded as an early Proterozoic arc fragment that collided with the La Ronge Domain along a destructive plate boundary (Lewry, 1981a and b; Lewry et al., 1987). The domain is largely delineated to the east by the Tabbernor Zone, a narrow "straight belt" comprising tightly appressed north-south folds, a prominent metamorphic gradient, early blastomylonites and later sinistral brittle faulting (Macdonald, 1976). Most of the western boundary is defined by subvertical mylonites, tectonic schists and late brittle faulting of the Stanley Shear Zone (Lewry, 1981a). These rocks become more flat lying and refolded in the northern part of the domain, where they form a high-strain detachment zone (Guncoat Gneisses) separating a structurally overlying fold-thrust package (Wapassini Allochthon) in the north from underlying granitoids and supracrustals (Iskwatikan Subdomain) further south (Lewry and Slimmon, 1985). This entire package of rocks is considered to have been subsequently complexly refolded and intruded by later plutons, resulting in the abundance of granitoid gneisses and plutons interspersed with narrow arcuate supracrustal belts characteristic of the Glennie Domain. The **Gee Lake Metavolcanic Belt** comprises one of these supracrustal belts.

Approximately 70 percent of the Gee Lake area is underlain by foliated to near-massive granitoid rocks of the **Lueder Lake Batholith** (Thomas, this volume) in the south half of the area and the **Wood Lake Batholith** (Kirkland, 1976) northeast of Gee Lake. Both intrusive complexes comprise mosaics primarily of granite, granodiorite and quartz diorite with minor interspersed aplogranite, diorite and pyroxenite bodies. The narrow Gee Lake Metavolcanic Belt stretches from Sadler Lake (20 km northwest of Gee Lake) through the northwest corner of the area, where it widens to a maximum of 5 km just west of Gee Lake. East of Gee Lake, the belt narrows and pinches out about 2 km east of the map area. The belt is dominated by mafic metavolcanics with subordinate intermediate metavolcanics and minor interlayered felsic metavolcanics and intravolcanic metasediments. The metavolcanics are structurally overlain to the northwest by a metasedimentary sequence of probable volcanogenic origin which extends another 15 km north of the map area.

2. Metavolcanic Rocks

a) Mafic Metavolcanics

Mafic metavolcanics (unit Mv) comprise approximately 70 percent of the metavolcanic rocks in the map area. The typically fine-grained dark green to black rocks contain plagioclase, minor quartz and varying amounts (>35 percent) of hornblende ± actinolite ± garnet. Local

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(1) Project funded under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89

recrystallization has formed areas of medium-grained hornblende gneiss containing hornblende porphyroblasts up to 5 mm in diameter. Overall fabric is commonly defined by penetrative, near-massive schistose foliation of the mafic minerals. This unit largely consists of massive flows and flow breccias with minor tuffaceous or greywacke horizons. Massive amygdaloidal flows occur locally throughout the unit but are more prevalent in the northwest. The typically round to oval amygdules are predominantly plagioclase filled and constitute up to 25 percent of the rock. They average 3 mm in diameter and are typically rodded to lengths of 2 to 3 cm. Pillowed flows are seldom recognizable, although a few isolated outcrops occur in the vicinity of mafic flow breccias. The pillows have a maximum diameter of 50 cm but typically average 15 to 25 cm across with visible rodded lengths up to a metre. The pillows are commonly altered, display epidotized and carbonatized cores, and at one locality about 3 km east of Gee Lake (UTM co-ordinates 599200mE, 6116400mN) are extremely silicified and pyritized. Pillowed flows typically grade into pillow breccias and flow breccias containing monolithic clasts averaging 10 to 15 cm across and abundant anastomosing calcite veins and cavity infillings.

b) Intermediate Metavolcanics

Intermediate metavolcanics (unit Iv) are locally interlayered with the mafic metavolcanics, although the majority occur in a 0.5 to 1.5 km wide zone structurally underlying the east and southeast margin of the mafic rocks. Felsic metavolcanics are commonly interlayered with this unit, particularly in the vicinity of Gee Lake. The rocks are typically fine grained with medium to dark grey weathered surfaces, and consist of quartz, plagioclase, and 15 to 35 percent mafic minerals including ubiquitous hornblende ± biotite ± actinolite ± garnet. Rock fabrics include near-massive, finely laminated and compositionally banded varieties, and the foliation is commonly defined by discontinuous streaky segregations of the felsic minerals. Most of the intermediate metavolcanics are volcaniclastic, including both pyroclastic and volcanogenic sedimentary deposits. Feldspar-phyric flows with euhedral to subhedral plagioclase up to 4 mm long occur rarely. Pyroclastic deposits are abundant and typically contain unsorted monolithic or more commonly heterolithic clasts which are mainly felsic, 0.2 to 5 cm in size and characteristically flattened parallel to the local foliation. In contrast, several outcrops contain clasts that appear undeformed in cross-

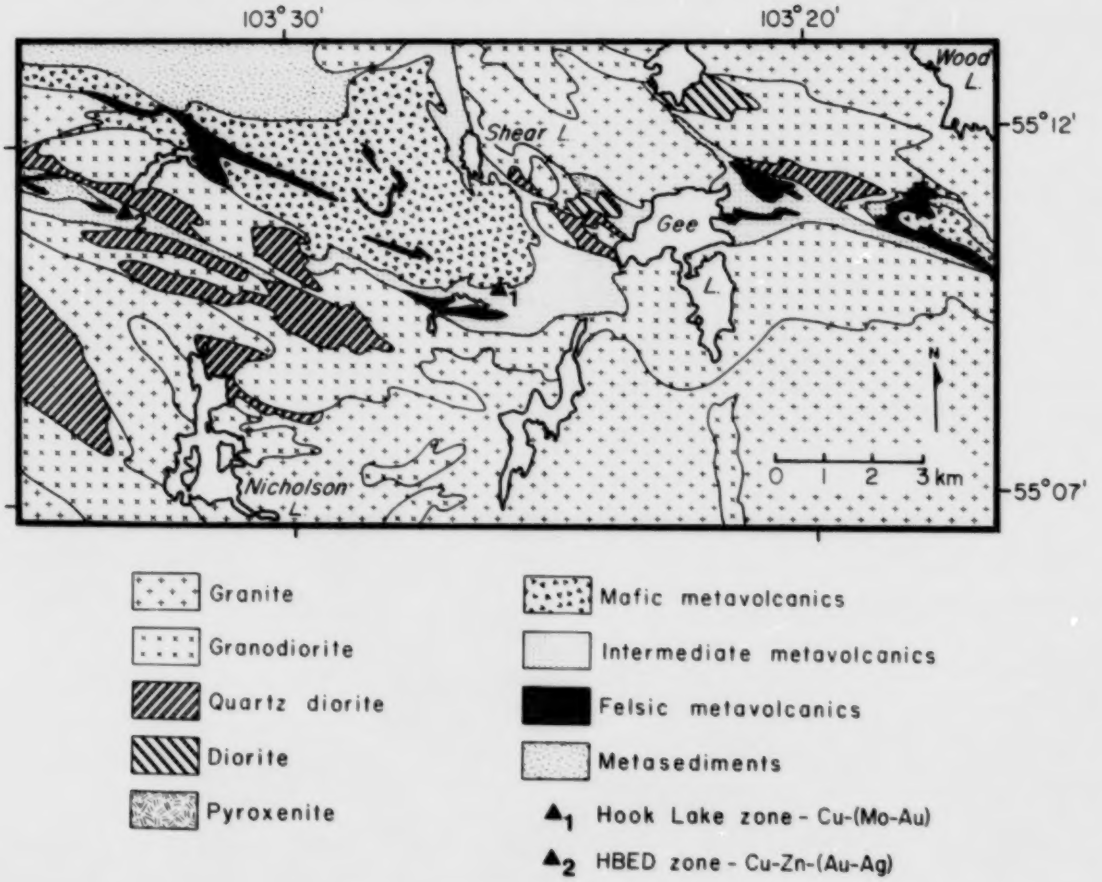

Figure 1 – General geology of the Gee Lake area.

crops contain clasts that appear undeformed in cross-section but which are strongly rodded with visible length to width ratios of at least 25:1. Intermediate ash and crystal tuffaceous horizons are locally intercalated with the coarser pyroclastics and only rarely is graded bedding preserved.

c) Felsic Metavolcanics

Felsic metavolcanics (unit Fv) include finely laminated and layered tuffs, fragmentals, and near-massive flows. The rocks occur as centimetre- to metre-scale intercalations in both the mafic and intermediate metavolcanics, and also as wider mappable horizons a few tens to a few hundred metres wide. These cream to light grey aphanitic to fine-grained rocks vary from rhyolitic to dacitic in composition and contain less than 15 percent mafic minerals. Traces of magnetite and pyrite are common in the rhyolitic horizons. Fragmental pyroclastic deposits typically contain flattened heterolithic clasts ranging from 1 to 10 cm in length and constituting up to 50 percent of the rock, but intensely rodded varieties also exist. The thicker rhyolitic flow-type horizons are near massive and normally magnetite rich.

d) Feldspar Porphyry

Feldspar porphyry (unit Fp) primarily intrudes the intermediate metavolcanics west of Gee Lake as narrow sill-like bodies of fine-grained light grey rock up to a few metres wide. Round plagioclase phenocrysts less than 4 mm in diameter constitute up to 30 percent and biotite less than 5 percent of the rock. Traces of pyrite are present locally.

e) Amphibolite

Amphibolite (unit Am) occurs as narrow sill-like bodies within the mafic metavolcanic rocks, primarily in a southeast-trending zone west of Shear Lake[1]. The majority of these massive to slightly foliated rocks are medium- to coarse-grained with up to 90 percent dark green to black hornblende and minor amounts of diopside, biotite and garnet.

3. Metasedimentary Rocks

a) Argillaceous Pelites

Argillaceous pelites (unit P) are almost completely restricted to the northwest portion of the map area where they structurally overlie the mafic metavolcanics. Rare intravolcanic horizons are isolated and of limited areal extent. Biotite averages 15 percent of these fine-grained brownish rocks, which contain a well-developed, commonly banded schistose foliation. Garnet, muscovite and rare sillimanite occur locally in minor amounts. **Staurolitic argillaceous pelites** (unit Ps) contain euhedral to subhedral staurolite porphyroblasts up to 4 cm long in a strongly schistose fine-grained biotitic matrix.

b) Meta-arkoses

Meta-arkoses (unit Ar) are mainly located in a lens-shaped body, 5 km northwest of Nicholson Lake, which is part of a narrow supracrustal septum separated from the main belt to the north. These uniformly granular fine-grained rocks contain 2 to 3 percent of both biotite and muscovite. Faint compositional millimetre- to centimetre-scale banding, typically accentuated by hematite-staining, may represent original sedimentary bedding. East of Gee Lake, meta-arkosic rocks are locally interlayered with the metavolcanics and are similar in appearance to the felsic metavolcanic rocks.

c) Calc-silicates

Calc-silicates (unit C) occur in limited amounts, generally associated with the metavolcanics in thin discontinuous diopside- and epidote-rich intercalations and boudinaged pods. Rare horizons up to 100 m wide consist of fine-grained light green diopside- and calcite-rich rocks. Local gossanous exposures contain 2 to 3 percent finely disseminated pyrite.

4. Intrusive Rocks

a) Granite

Granite (unit G) is the most abundant rock in the composite intrusive complexes. These pink to light grey medium-grained rocks have a fabric typified by a weak to moderate alignment of biotite, which makes up 5 to 10 percent of the rock. Other prominent minerals are rare hornblende, up to 3 percent epidote and common traces of magnetite. Crosscutting and *lit-par-lit* apophyses commonly intrude the country rocks and local intrusion breccias occur along margins. Metavolcanic xenoliths are most common along the margin of the Wood Lake Batholith and typically parallel the local foliation. Medium- to coarse-grained granitic pegmatites of limited areal extent mainly cut granite and granodiorite as sharp-walled irregularly shaped intrusions.

In the Lueder Lake Batholith, an extensive area of **porphyritic granite** (subunit Gp) underlies the area south and southeast of Gee Lake and a smaller area just northwest of Nicholson Lake. These rocks contain euhedral K-feldspar phenocrysts that parallel the foliation and average 2 cm in length. Foliation is typically less well developed and grain size is coarser in the porphyritic rocks.

b) Granodiorite

Granodiorite (unit Gd) is intruded by the granite and normally has a more well-developed, locally gneissic foliation. These cream to light grey medium-grained rocks comprise a granodiorite to tonalite compositional mixture with K-feldspar content averaging 5 to 15 percent. Mafic minerals include 5 to 10 percent biotite and 25 per-

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(1) Unofficial lake name

cent hornblende. Epidote and magnetite are commonly present in trace amounts.

c) Quartz diorite

Quartz diorite (unit Qd) is similar in appearance to the granodioritic rocks and is normally separated from them by gradational boundaries. These rocks are slightly more mafic than the granodioritic rocks and average 5 to 10 percent biotite and 30 percent hornblende. Euhedral hornblende crystals up to 5 mm long commonly parallel the foliation. Quartz comprises 10 to 15 percent of the rock and traces of epidote occur locally.

d) Diorite

Diorite (unit Di) occurs as relatively rare, poorly foliated bodies up to 1 km in diameter that generally grade into quartz diorite or granodiorite. Ubiquitous hornblende, with local euhedral crystals up to 1 cm long, lesser amounts of diopside and minor biotite combine to give an average of 40 percent mafic minerals in these medium- to coarse-grained rocks. Traces of epidote, magnetite and pyrite occur locally.

e) Pyroxenite

Pyroxenite (unit Px) constitutes two small, typically massive bodies closely associated with dioritic rocks in the Wood Lake Batholith. These coarse-grained rocks contain nearly 100 percent diopside, locally with euhedral crystals up to 2 cm across, and minor hornblende and biotite. Magnetic susceptibility of these rocks is commonly an order of magnitude higher than the surrounding more felsic rock types.

f) Aplogranite

Aplogranite (unit Ga) occurs only in the Lueder Lake Batholith where it intrudes both granite and granodiorite as narrow dykes and sill-like sheets less than 50 m wide. These pink to salmon-coloured fine-grained rocks are typically massive to very slightly foliated and contain less than 3 percent biotite and local muscovite.

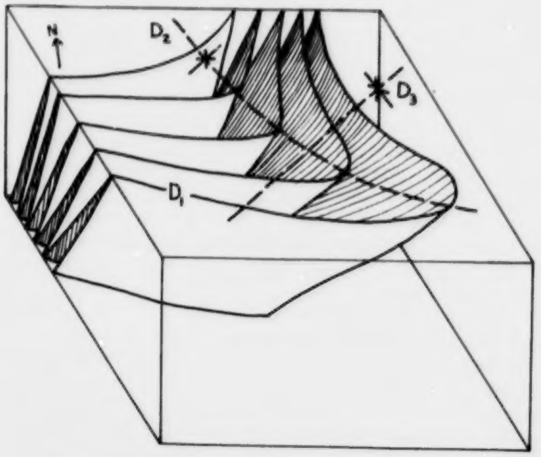

Figure 2 – Block diagram showing schematic S_1/D_1 foliation surfaces of metavolcanic rocks west of Gee Lake refolded by D_2 and D_3 events.

5. Structural Geology

The Gee Lake area has undergone polyphase deformation that has variably preserved the primary volcanic features, including pillow flows and breccias, unsorted lapilli and bomb pyroclastic deposits as well as graded and layered tuffaceous horizons. An early, dominantly northwest-striking penetrative schistose foliation (S_1) is generally parallel to primary layering (S_0) in the supracrustals The S_0/S_1 foliation is related to an early deformational event (D_1) which produced tight to isoclinal folds that are slightly overturned to the south. In the intrusive rocks, axial planar cleavage foliation developed parallel to the intrusion boundaries and the S_1 supracrustal fabric during D_1.

Another deformational event (D_2) produced folding on slightly more northerly-striking axial surfaces than those of D_1. The main exposure of the Gee Lake Metavolcanic Belt is a northwest-plunging upright synformal structure related to D_2 folding (Figure 2). The nose of the structure is overturned to the south in the region immediately southwest of Gee Lake. Minor fold axes in the area parallel the major D_2 fold axis. The majority of the metavolcanic rocks comprise L-tectonites with intensely stretched b-lineations (L_1), presumably developed by rotation during D_2, which parallel the D_2 minor fold axes (Figure 3). Extreme rodding of pillows and pyroclastic fragments is common and visible length to width ratios locally exceed 25:1. Both the L_1 and refolded S_1 fabrics are more steeply inclined in the hinge region away from the synformal closure. A somewhat less steeply plunging L_1 fabric is present in the supracrustal rocks east of Gee Lake.

A third deformational event (D_3) has produced folding along southwest-trending axial surfaces. Rare open minor folds, which appear to be related to this event, plunge steeply to the southwest.

A number of prominent airphoto lineaments, which trend parallel or slightly obliquely to local foliations, possibly represent thrust surfaces related to D_1. Evidence of shearing preserved along the metavolcanic/intrusive margin west of Gee Lake may be associated with intrusion emplacement. Late brittle fracturing (D_4) has a dominant northeast trend and a sinistral sense of displacement.

6. Metamorphism

Coexistence of garnet, staurolite and local sillimanite in pelitic rocks indicates that lower to middle amphibolite facies grades were attained and probably maintained during the D_1 to D_3 events. Epidote veining and chloritization of hornblende and biotite along some of the D_4 structures indicate localized retrogression to upper greenschist facies.

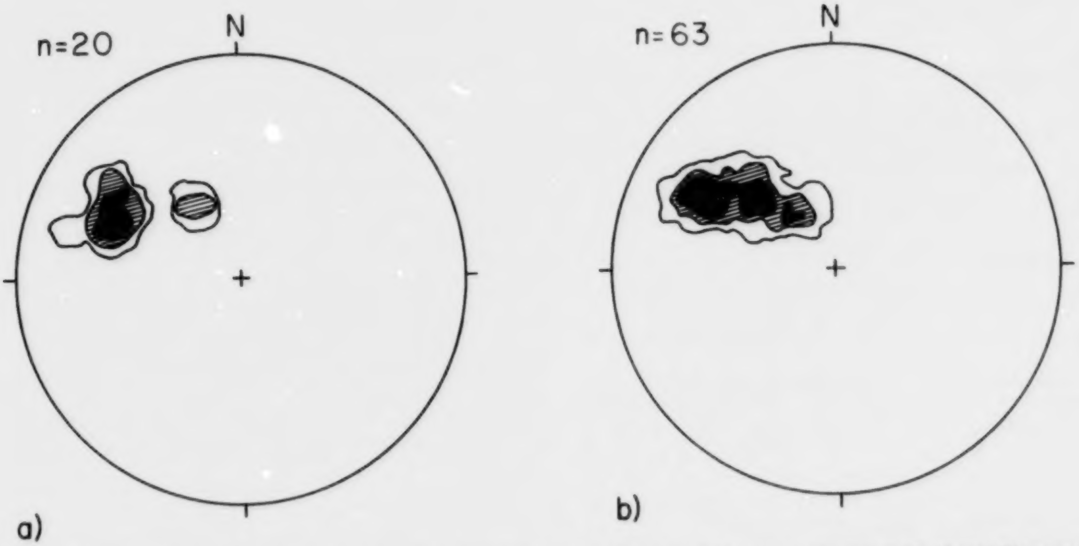

Figure 3 - Lower-hemisphere equal-area stereographic projections: a) D_2 minor fold axes, contoured at 10, 15 and 20 percent per 1 percent area; b) L_1 b-lineations, contoured at 5, 10 and 15 percent per 1 percent area.

7. Economic Geology

Mineral exploration in the area began in the early fifties and has been primarily restricted to the Gee Lake Metavolcanic Belt. Two principal mineralized areas, the **Hook Lake**[1] and **HBED**[1] zones (Figure 1), were discovered mainly through ground EM surveys and diamond drilling. The Hook Lake zone contains significant copper and anomalous molybdenum mineralization, while the HBED zone contains significant mineralized zones of both copper and zinc. Minor amounts of gold are also present in both zones.

a) Hook Lake Zone

Exploration in this area began in 1951 when G.F. Thompson drilled two holes northeast of Hook Lake[1]. Assessment work indicates only the presence of pyrite in the core (Assessment File 63M03-0006, Saskatchewan Energy and Mines, Regina).

In 1954, Hudson Bay Exploration and Development (HBED) conducted an EM survey over the Hook Lake area. Three holes were drilled to test some of the anomalies that make up a northwest-trending linear conductive zone extending from 2 km northeast of Hook Lake to 3 km northwest of Hook Lake. Pyrite, pyrrhotite and graphite mineralization is reported in the core, which was selectively assayed for Au, Ag, Cu, Zn and Ni. The best intersection encountered 0.01 oz./ton Au over 1.46 m, reportedly in sheared siliceous sediments (Assessment File 63M03-0002).

An EM survey conducted by HBED in 1967 extended the Hook Lake conductive zone another 3 km along strike to the northwest. Sample assays returned traces of Au, Ag, Cu and Zn in nine diamond-drill holes that intersected narrow concentrations of up to 50 percent pyrite and 30 percent pyrrhotite in hornblende gneiss (Assessment File 63M03-0014).

In 1969, A.L. Parres reported results from horizontal and vertical loop EM surveys conducted between Hook and Gee Lakes. Several conductors were tested by 24 drillholes which intersected visible pyrite, pyrrhotite and chalcopyrite mineralization. Samples assayed maximum Au values of 0.03 oz./ton over 2.44 m and 0.06 oz./ton over 0.3 m, and Cu values of 8.19 percent over 0.3 m and 5.82 percent over 0.91 m. The mineralization is associated with both quartz veining and massive sulphide zones in hornblende schist. Molybdenum is present in zones with maximum assays of 0.33 percent over 2.44 m, and Ag, Ni and Zn occur sporadically in minor amounts (Assessment File 63M03-0019).

HBED returned to the area in 1980 and 1981 and conducted another EM survey that delineated three new conductors which were subsequently drilled. Visible pyrite, pyrrhotite, chalcopyrite and graphite mineralization is recorded in the drill logs, along with assays reporting traces of Au, Ag, Cu, Zn and Ni (Assessment File 63M03-0027).

Most of the conductors delineated in the Hook Lake area occur along prominent lineaments and are probably fracture controlled, although some are stratabound, coinciding with felsic metavolcanic horizons. The lineament system extends for several kilometres northwest of the main Hook Lake zone and continues west of the

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(1) Unofficial name

map area. Much of this area has not yet been covered by EM surveys. Mineralization in felsic metavolcanics in the vicinity primarily consists of finely disseminated pyrite.

b) HBED Zone

In 1968, HBED completed an EM survey over the supracrustal rocks separated from the main metavolcanic belt at the west edge of the map area. Two major conductive zones were discovered that converge between two small lakes in the area. The conductors coincide approximately with two bands of felsic metavolcanic rocks possibly belonging to the same folded horizon. Several short conductors, comprising the main HBED zone, occur at the southeast extension of the main conductive zone and may represent the southern limb of the same felsic horizon. A total of twenty diamond-drill holes tested most of the conductors, but the most significant results are from the HBED zone. Drill records from this zone reported visible pyrite, pyrrhotite, chalcopyrite, sphalerite, galena and graphite, and samples assayed up to 3.33 percent Cu and 5.5 percent Zn over 0.61 m. The maximum Au value obtained was 0.02 oz./ton over 0.4 m, associated with up to 1.36 oz./ton Ag over 0.98 m. Mineralization is reportedly associated with quartz sericite schist (possibly sheared felsic metavolcanics) (Assessment File 63M04-0004).

c) Suggested Exploration Targets

Further detailed mapping is warranted in both the Hook Lake and HBED zones to determine the local structure and extent of mineralization. Additional EM surveys could be carried out to determine the northwest extent of conductors along the Hook Lake lineament system and the southeast extent of the HBED zone. Particular attention might be given to areas of felsic metavolcanics, as mineralization is commonly associated with them. A grab sample taken this summer from one of the conductive felsic metavolcanic horizons north of Hook Lake (UTM co-ordinates 599300mE, 6115200mN) assayed 36 ppb Au.

Several silicified gossanous outcrops containing finely disseminated pyrite are present along the north-northwest-trending lineament system passing through Shear Lake. Much of this area has not been covered by EM surveys and, consequently, the extent of any possible conductors is unknown. A grab sample taken this summer from a mineralized quartz vein in sheared rocks along this system at the west shore of Gee Lake (UTM co-ordinates 602200mE, 6115600mN) assayed 0.46 percent Mo.

Local gossanous zones containing pyrite and magnetite occur in the felsic metavolcanic rocks 3 km east of Gee Lake. A strong lineament with local shearing comprises the southern margin of this metavolcanic package and may be related to the mineralization.

8. References

Hornbrook, E.H.W., Garrett, R.G., Lynch, J.J. and Beck, L.S. (1975): Regional lake sediment geochemical reconnaissance data, east-central Saskatchewan (63M, 64D and parts of 73I, O, P and 74A); Geol. Surv. Can., Open File 266, 108p (52 maps at 1:250,000 scale).

________ (1977): Regional lake sediment geochemical reconnaissance data, east-central Saskatchewan (NTS 63M, 64D and parts of 63K, L, N, 73I, O, P and 74A); Geol. Surv. Can., Open File 488 (12 maps at 1:250,000 scale).

Hornbrook, E.H.W., Lynch, J.J., Friske, P.W.B., Lund, N.D. and Schmitt, H.R. (1985): Regional lake sediment geochemical reconnaissance data (NTS 63M, 64D and parts of 63K, L, N, 73I, O, P and 74A); Geol. Surv. Can., Open File 1129, 150p (8 maps at 1:250,000 scale).

Kirkland, S.J.T. (1976): The geology of the Manawan Lake area (south half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 172, 24p.

Lewry, J.F. (1981a): La Ronge Project: II. Geology of the Stanley Shear Zone; *in* Summary of Investigations 1981, Sask. Geol. Surv., Misc. Rep. 81-4, p28-33.

________ (1981b): Lower Proterozoic arc-microcontinent collisional tectonics in the western Churchill Province; Nature, v294, no5836, p69-72.

Lewry, J.F. and Slimmon, W.L. (1985): Compilation bedrock geology, Lac La Ronge, NTS area 73P/73I; Sask. Energy Mines, Rep. 225 (1:250,000 scale map with marginal notes).

Lewry, J.F., Thomas, D.J., Macdonald, R. and Chiarenzelli, J. (1987): Structural relations in accreted terranes of the Trans-Hudson Orogen, Saskatchewan: telescoping in a collisional regime (abstract); Geol. Assoc. Can./Mineral. Assoc. Can., Joint Annu. Meet., Saskatoon, May 1987, Prog. Abstr., v12, p67.

Macdonald, R. (1976): Compilation geology, Pelican Narrows (63M) and Amisk Lake (63L); *in* Summary of Investigations 1976, Sask. Geol. Surv., p53-57.

________ (1981): Compilation bedrock geology: Pelican Narrows and Amisk Lake areas; 1:250,000 scale prelim. map with Summary of Investigations 1981, Sask. Geol. Surv., Misc. Rep. 81-4.

Schreiner, B.T. (1984): Quaternary geology of the Pelican Narrows area (NTS 63M, N); Sask. Energy Mines, Open File Rep. 84-3 (1:250,000 scale map with marginal notes).

Scott, B.P. (1981): Geology of the Maynard Lake - Sandy Narrows (west) area; Sask. Miner. Resour., Rep 186, 26p.

Taylor, F.C. (1958): Pelican Narrows, Saskatchewan; Geol. Surv. Can., Map 1-1958 (1:253,440 scale map with marginal notes).

Project 8836

Glennie-Kisseynew P-T Study 1988: Fieldwork and Preliminary Results[1]

Dexter Perkins[2]

Perkins, D. (1988): Glennie-Kisseynew P-T study 1988: fieldwork and preliminary results, *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

During August 1987, preliminary fieldwork was conducted in the Pelican Narrows area of northeastern Saskatchewan (Figure 1). Analytical results and application of some conventional geothermobarometers indicate that the rocks have retained chemical signatures of high-grade metamorphism. A joint venture agreement between the University of North Dakota and Saskatchewan Energy and Mines was negotiated. The goal was to investigate the pressures and temperatures of metamorphism recorded by rocks in a 5000 km^2 area centred around Pelican Lake.

1. Region of Interest

The area covered by field work during 1988 is approximately rectangular. The northern border coincides with the Churchill River system (Ourom, Iskwatam, Wintego, Pita and Sokatisewin Lakes); the southern border follows a line connecting Brownell, Deschambault and Jan Lakes. To the west, the area extends to Trade and Sadler Lakes; the easternmost samples were collected along the road connecting Pelican Narrows to Sandy Falls.

Because metamorphosed granites and basalts tend to be of little use in determining metamorphic pressures and temperatures, emphasis was placed on the study of metasedimentary rocks. Based on the compilation map of Macdonald (1981) and, to a lesser extent, the more detailed work of several other workers (including Kirkland, 1957, 1958, 1976a, 1976b; Johnson, 1966; Pyke, 1966; Sibbald, 1978; Scott, 1981), important metasedimentary areas were identified. Outcrops were visited via air and water, and over 800 samples were collected from approximately 20 different lakes and rivers. Thin sections are presently being made for about 200 samples. Garnet and biotite have already been semi-quantitatively analyzed in about 25 sections, using EMPA to calculate metamorphic temperatures.

2. Lowest Grade Rocks

The rocks collected vary in metamorphic grade from greenschist to granulite facies. The lowest grade rocks were collected just east of the trace of the Tabbernor Fault on the shores of Ourom, Manawan and Wood Lakes. In outcrop, some of these lowest grade rocks appear little deformed or metamorphosed, but thin sections reveal the presence of metamorphic chlorite, muscovite and andalusite. Andalusite was observed in outcrop at three locations: 1) 2.5 km southeast of the Wood Lake Indian Reservation, 2) in the woods approximately 3 km east of Piney Lake, and 3) at the southernmost end of Pelican Lake near the portage to Deschambault Lake. Andalusite, staurolite and quartz coexist at the Piney Lake locality, suggesting metamorphic pressure and temperature of about 3 kbar and 550°C (Thompson, 1976; Winkler, 1979). Staurolite-quartz assemblages were also found in the vicinity of Brownell and Staurolite Lakes. However, at those locations the stable Al_2SiO_5 polymorph is sillimanite, suggesting pressures in excess of 3 kbar at 525 to 600°C (Holdaway, 1971).

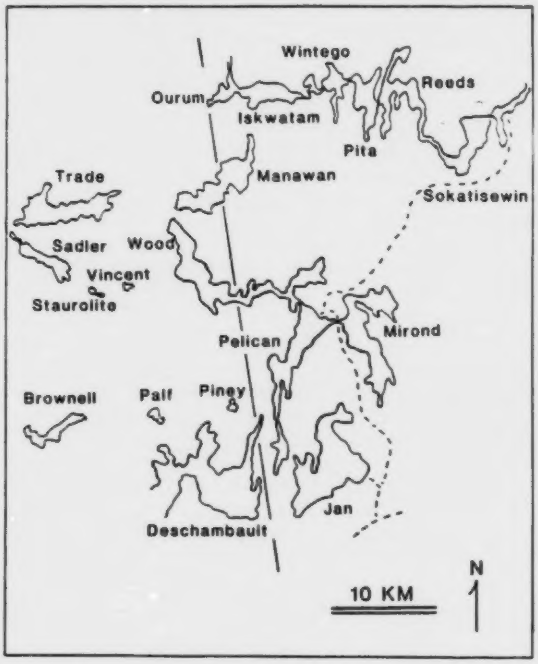

Figure 1 - Pelican Narrows area, showing lakes visited during the summer of 1988. Solid line represents the trace of the Tabbernor Fault; dashed lines are roads.

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[1] Joint venture project with partial support provided by the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89

[2] Department of Geology and Geological Engineering, University of North Dakota, Grand Forks, North Dakota 58102

3. Highest Grade Rocks

The highest grade rocks encountered are garnet-sillimanite-bearing Kisseynew gneisses. These gneisses must have formed at temperatures in excess of 600°C and at pressures of 4 to 7 kbar. Only two samples of sillimanite-bearing Kisseynew gneiss have been identified so far. More will probably be found when all the thin sections are made. The general appearance of the Kisseynew gneiss suggests uniform metamorphic conditions across most of the northeastern portion of the study area.

Sillimanite has also been found in other lithologic units. In particular, one sample collected near Palf Lake and another from an outcrop between Vincent and Staurolite Lakes appear to contain visible sillimanite. Garnet is absent in both specimens.

4. Regional Variation in Grade

Based upon some key minerals and assemblages, some of which were summarized above, it appears that metamorphic grade is relatively uniform to the east of the Tabbernor Fault, but changes rapidly over short distances near the Tabbernor Fault and in metasediments associated with greenstone units to the west of the fault. Such variations in grade may be primary, due to variations in pressure and temperature at the time of metamorphism, but may also be due to postmetamorphic tectonism. There are many examples of high-strain zones which may represent postmetamorphic deformation. More detailed mapping is needed.

5. Geothermometry

Semiquantitative analyses of garnet and biotite were obtained from about 25 thin sections. The distribution of Fe and Mg between coexisting garnet and biotite was used to deduce metamorphic temperatures (Perchuk and Lavrent'eva, 1983). The specifics of these results must be regarded with caution inasmuch as the analyses are attended by rather large uncertainties. High-quality analyses will be obtained this winter.

The preliminary results (Figure 2) are sufficiently reliable, however, to suggest attainment of metamorphic temperatures in excess of 625 to 650°C to the east of the Tabbernor Fault, and in the range 550 to 600°C to the west. The results also suggest that there are no major regional variations in metamorphic temperatures other than those associated with the fault. It is particularly interesting to note that there appears to be no "thermal high" associated with the orthopyroxene-bearing Sahli Granite unit between Mirond and Pelican Lakes. If detailed geothermometry supports this observation, it suggests metamorphic (re)equilibration after emplacement of the Sahli Granite.

6. Ongoing Work

During the winter of 1988–89, all thin sections will be made and quantitative analyses of key minerals will be obtained. Several different geothermometers and geobarometers, based primarily on equilibria involving garnet, biotite, cordierite and sillimanite, will be applied. Once those results have been obtained, plans for the next field season will be made.

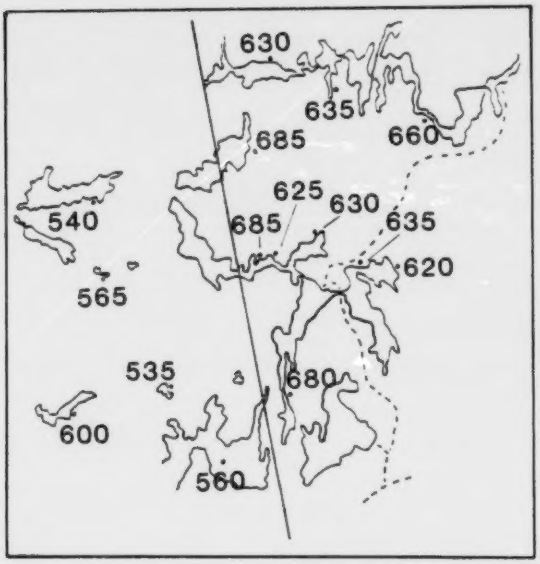

Figure 2 – Garnet-biotite temperatures based on the calibration of Perchuk and Lavrent'eva (1983). For clarity, a few calculated tempertures have been omitted from the centre of the area, as they fall in the same range. Solid line represents the trace of the Tabbernor Fault.

7. References

Holdaway, M. J. (1971): Stability of andalusite and the aluminosilicate phase diagram; Am. J. Sci., v271, p97-131.

Johnson, R.L. (1966): The geology of the Nemei Lake area (west half); Sask. Dep. Miner. Resour., Rep. 107, 24p.

Kirkland, S.J.T. (1957): The geology of the Manawan Lake area (north half); Sask. Dep. Miner. Resour., Rep. 27, 12p.

Kirkland, S.J.T. (1958): The geology of the Deschambault Lake area (east half), Saskatchewan; Sask. Dep. Miner. Resour., Rep.31, 16p.

Kirkland, S.J.T. (1976a): The geology of the Marchel–Wintego–Sandy Bay area, Saskatchewan; Sask. Dep. Miner. Resour., Rep.172, 12p.

Kirkland, S.J.T. (1976b): The geology of the Manawan Lake area (south half), Saskatchewan; Sask. Dep. Miner. Resour., Rep.175, 14p.

Macdonald, R. (1981): Compilation bedrock geology: Pelican Narrows and Amisk Lake areas; *in* Summary of Investigations 1981, Sask. Geol. Surv., p.16-23.

Perchuk, L.L. and Lavrent'eva, I.V. (1983): Experimental investigation of exchange equilibria in the system cordierite-garnet-biotite; *in* Saxena, S.K.(ed.), Kinetics and Equilibrium in Mineral Reactions; Springer-Verlag, New York, p111-129.

Pyke, M.W. (1966): The geology of the Pelican Narrows and Birch Portage areas, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 93, 68p.

Scott, B.P. (1981): Geology of the Maynard Lake - Sandy Narrows (west) area; Sask. Dep. Miner. Resour., Rep. 186, 26p.

Sibbald, T.I.I. (1978): Geology of the Sandy Narrows (east) area, Saskatchewan; Sask. Dep. Miner. Resour., Rep.170, 49p.

Thompson, A.B. (1976): Mineral reactions in pelitic rocks: I. prediction of P-T-X(Fe-Mg) phase relations; Am. J. Sci., v276, p401-454.

Winkler, H.G.F. (1979): Petrogenesis of Metamorphic Rocks (5th ed.); Springer-Verlag, New York; 348p.

Project 8801

Observations on Deformation in the Glennie Domain and Hanson Lake Block[1]

J.F. Lewry [2] and R. Macdonald

Lewry, J.F. and Macdonald, R. 1988: Observations on deformation in the Glennie Domain and Hanson Lake Block; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

This summer, the authors spent about two weeks together examining mainly lakeshore exposures in several locations peripheral to areas of current detailed remapping in the Glennie Domain (Delaney, Thomas, Slimmon, this volume), as well as examining parts of the Pelican-Mirond Lakes area in the Hanson Lake Block. The principal aims were to define possible eastward extensions of the mylonitic Guncoat Gneisses (Lewry, 1981; Lewry and Slimmon, 1985) and locate or confirm other possible ductile high-strain zones in the region.

1. Pelican-Mirond Lakes Area

Our objective in this area was to attempt to define more precisely the margin of the Hanson Lake Block in terms of bounding ductile shear or high-strain zones. In order to do this, we examined a number of localities around Pelican Narrows, tracing in detail the progression from lesser to more deformed gneisses, and as a result have recognized the existence of zones of feldspathoclastic mylonite *sensu lato* which possibly separate a lower Archean window within the Hanson Lake Block from an overlying Early Proterozoic sequence.

The northern end of the Hanson Lake Block, centred about Pelican Narrows, is underlain mainly by granodiorites, feldspathoblastic hornblendic and biotitic gneisses, and quartzofeldspathic gneisses of possible psammitic origin containing mafic sill-like layers, all of which structurally overlie the domal Archean Sahli Granite to the south (Macdonald, 1974, 1975, 1981).

a) Pelican Narrows Microwave Tower Locality

Migmatite:

A key to understanding the nature of the protolith in this area is provided in freshly burned exposures of neosome-dominant migmatized rocks which occur around the microwave tower about 5 km northwest of Pelican Narrows. Paleosomes in these exposures include well-foliated layered amphibolite, hornblende gneiss and hornblendic calc-silicate gneiss, collectively interpreted mainly as metavolcanics, and varied medium- to coarse-grained mafic to ultramafic amphibolites, metadiorites and metagabbros believed to be plutonic. These occur in angular to well-rounded blocks, boudinaged and folded strips, and more extensive screens of varying size. The dominant tonalite-granodiorite neosome is schlieric to nebulitic, locally porphyritic and generally exhibits at least a weak foliation.

Pegmatites:

This migmatitic assemblage is extensively invaded by irregular anatectic-type coarse K-feldspar pegmatites and more uniform pink granite bodies on all scales. Another prominent feature is the presence of numerous K-feldspar porphyroblasts which appear to be temporally related to pegmatite development. The porphyroblasts vary irregularly in size and distribution; some of the largest are 10 cm across. Many porphyroblasts are subrounded to subovoid, suggesting, in common with some of the rounded xenoliths, that rotational movement and tectonic "corrosion" took place during a ductile shearing phase. It is clear from the exposures that folding and the foliation development both preceded and followed intrusion of the granite and the production of the pegmatite in a deformational continuum.

b) Pelican Narrows to "Chachukew Narrows"

A section was examined along the north shore of Pelican Lake from Pelican Narrows northwest to the first narrows on the way to Chachukew Lake, a distance of about 3 km. Lakeshore exposures encountered over the first kilometre or so comprise gneissic tonalite-granodiorite similar to the main neosomal component at the microwave tower, but are generally finer grained and more uniform. Some of these rocks were originally interpreted as possible pelitic gneisses (Macdonald, op. cit.).

Origin of the Feldspathoclasts:

The gneissic tonalite-granodiorite contains sporadic larger crystals and coarse crystalline aggregates of plagioclase and K-feldspar, generally up to about 2 or 3 cm in size but locally larger, which are randomly orientated and rounded to rectanguloid-ovoid in form. In rock faces subparallel to the lineation (X-Z plane), which in this area generally plunges to the northeast, the megacrysts commonly have a "winged" asymmetric form and straight to curving dynamic recrystallization tails. We interpret these as rotationally strained porphyroclasts or feldspathoclasts. These include both plagioclase from a tonalite-granodiorite protolith, and

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generally larger K-feldspars derived, for the most part, from isolated porphyroblasts and by extreme disruption of pegmatite sheets and lenses of the type encountered at the microwave tower. The lineation is regarded as an extensional lineation.

Balled Mafic Xenoliths:

Rounded amphibolite and mafic gneiss inclusions also occur in this section and on islands to the south, ranging from about football size to a metre or more in size. These are typically enwrapped by gneissic tonalite-granodiorite and also show the effects of rotational strain.

Pegmatite Mylonite:

Towards the narrows leading to Chachukew Lake, there is a profusion of pegmatites of several generations, ranging from earliest tectonic to posttectonic. The strain in these pegmatites and migmatites is extremely variable. In places, as at the western point of the narrows and on the island in the narrows, stronger mylonitization in pegmatite has produced a distinctive rock consisting of densely packed, small peanut to semolina-sized porphyroclasts within a subordinate mylonitic matrix.

Straightening Zone:

There is a a general but uneven increase in ductile shear strain towards the narrows, marked not only by rotational strain effects, decrease in grain size and generation of a prominent pervasive stretching lineation, but also by the development of strongly foliated and commonly banded gneisses which are transposed into a straight belt (a feature previously noted by Macdonald, op. cit.), comprising interbanded protomylonitic to mylonitic porphyroclastic felsic gneisses and subordinate amphibolitic gneiss. This high-strain zone is on strike to the south with the "Hornblende Gneiss Series" of Sibbald (1978) and the mixed P and M units of MacQuarrie and Macdonald (1978).

c) Mirond Lake

Exposures were examined in a section west to east across Mirond Lake, commencing with the margin of the charnockitic Sahli Granite. Mafic sheets occur in quartzofeldspathic gneisses immediately adjacent to the granite (unit QM of Macdonald, 1974, 1975).

The mafic sheets, which are also well exposed on the road between Pelican Narrows and Opawikusehikan Rapids, are clearly hypabyssal. Deformation in these bodies is quite variable: some are sharp walled and exhibit apparently chilled margins in places, and others are balled up and rootless. Internal strain is also variable.

The quartzofeldspathic gneisses vary from leucocratic fine-grained psammitic-looking rocks to more banded "grey gneisses". Biotite is the only dark mineral present. The general impression is that these are highly deformed rocks possibly derived from plutons, but in many respects they resemble metasediments with subtle colour and textural changes in the layers, some of which contain garnets.

On the east side of Mirond Lake there is more lithological variation. Banded grey gneiss gives way to a very mixed mafic/ultramafic to pelitic sequence; carbonate rock in lenses as much as 40 cm thick is exposed at low water. We speculated whether this may have been a volcanic or even mélange sequence. The next exposures to the west are convincing and spectacular feldspathoclastic mylonites. The extreme eastern exposures are of a quite uniform garnet-biotite gneiss which has been variously strained to about the protomylonitic stage and has many similarities to the Guncoat Gneisses.

d) Pelican Lake West

A brief visit was made south on Pelican Lake, along the west side of the Sahli Granite, just north of where the lake becomes constricted at Sandy Narrows. The purpose of this visit was to examine out the nature of the gneisses mapped by MacQuarrie (in MacQuarrie and Macdonald, op. cit.) as "hornblendic supracrustal rocks, largely metapyroclastics" (units P and M). Exposures of MacQuarrie's Pb unit ("feldspathoblastic hornblende-biotite gneiss, layered and laminated") are very similar to those found on the Chachukew Narrows traverse, comprising mainly feldspathoblastic tonalite-granodiorite in various stages of heterogeneous strain. A narrow band in MacQuarrie's PK unit ("potassium feldspar-porphyroblast hornblende gneiss") is similar to the quartzofeldspathic gneisses (Macdonald's unit QM), and again we were uncertain whether these are psammitic gneisses or deformed plutonic rock.

e) Regional Analysis, Hanson Lake Block

Our observations confirm that at least some of the rocks in the Pelican – Mirond Lakes area have undergone very high ductile strain and largely comprise protomylonitic to locally ultramylonitic feldspathoclastic and "straight" gneisses derived from plutonic, migmatitic and supracrustal protoliths.

The regional setting, relative age relationships, deformational style and protoliths of the northern end of the Hanson Lake Block are similar to those occurring adjacent to the basement inliers at Nistowiak Lake and Hunter Bay in the southwest of the Glennie Domain (Chiarenzelli et al., 1987), where ductile high-strain zones defined as the Nistowiak Gneisses are interpreted as forming detachment soles separating underlying reworked Archean basement from overlying Early Proterozoic allochthonous nappe sheets.

The Sahli Granite was recognized some time ago as an Archean body by Bell and Macdonald (1982). The Hanson Lake Block was established on the hypothesis that it represented an Archean block of greater extent than the Sahli Granite alone. At that time it was thought, on the basis of the Rb-Sr work of Coleman (1970), that the Hanson Lake Volcanics, and by extrapolation the Northern Lights Volcanics, were also Archean and they were accordingly assigned to the block. The northern margin of the Hanson Lake Block was defined by the western margin of the belt of straightened gneisses passing northwards from the western side of Jan Lake through Sandy Narrows, connecting through to the flaggy mylonitic rocks at "Chachukew Narrows". The boundary of the Hanson Lake Block east from Chachukew has always been less well defined, but was considered to join up eventually on the east with the Sturgeon-Weir high-strain zone.

It has become apparent, as a result of this summer's observations, that the size of the Archean window beneath a possible mylonitic sole may be smaller than the Hanson Lake Block as originally defined. We will refer to this new feature as the Pelican Window. We also assume that the upper margin of this window is defined by a sole of mylonitic rocks *sensu lato*, which includes the belt of gneisses passing through Sandy Narrows and "Chachukew Narrows" on the west and similar rocks in the southeast, approximately coincident with the Sturgeon-Weir lineament, which have been recently identified by Ashton (1987).

Many but not all of the gneisses in the marginal sole thus defined contain feldspathoclasts. In an attempt to define the extent and geometry of the highly strained rocks overlying the Pelican Window, an office compilation at 1:125,000 scale is in progress which will use the presence of feldspathoclasts (or at least feldspathoblasts) recorded in earlier reports as one criterion for recognizing the possible presence of ductile high-strain zones.

Interim results of this compilation have already demonstrated an apparent southward closure of the sole zone in the south, passing immediately north of the Hanson Lake and Northern Lights Volcanics. These volcanics may now be recognized as an Early Proterozoic package overlying the sole. Recent dating by Bickford et al. (1987) of samples taken at the Coleman (1970) sites in these volcanics has already provided appropriate Early Proterozoic U-Pb zircon ages for this above-sole assemblage. If there is indeed complete closure of a main mylonitic sole zone in the Hanson Lake Block, then the high-strain zone along the Sturgeon-Weir lineament is likely to represent a higher level listric splay rooting in this zone.

2. Grand Rapids – Keg Lake – Trade Lake

This part of the Churchill River was examined in an attempt to trace extensions of the Guncoat Gneisses exposed farther west. The Guncoat Gneisses comprise a distinctive belt of highly strained generally feldspathoblastic mylonites *sensu lato* which are considered to separate major thrust sheets farther west in the Glennie Domain (Lewry, 1981; Lewry and Slimmon, 1985; Lewry et al., 1987). From our observations we conclude that the Guncoat Gneisses *sensu stricto* are virtually absent from the area, but that similar ductile strains have been taken up in other rock types.

a) Keg Lake Section

A traverse was conducted across the supracrustal belt passing through the central part of Keg Lake, north of Stewart Island, with the primary objective of finding the extension of the Guncoat Gneisses (mylonitic feldspathoclastic pelite diatexite) which were expected to lie on strike through Keg Lake. In fact, little trace of Guncoat-type gneiss could be found, no doubt because of the paucity of an appropriate protolith.

In the south, near Stewart Island, moderately foliated, medium- to coarse-grained, homogeneous granodiorite-tonalite (unit 7 of Chakrabarti, 1968) contains injections of inequigranular granite pegmatite and leucogranite, with related local large K-feldspar porphyroblasts. Although these rocks are more strongly foliated and disrupted to the north, a major strain gradient is not evident.

The first supracrustal rocks encountered to the north comprise a narrow belt of psammopelitic metagreywackes and interlayered pelitic gneisses. The psammopelites are medium to fine grained, granoblastic and generally finely layered. Local interlayers of coarser ribbon-foliated pelitic garnet-biotite gneiss occur on a several centimetre to metre scale. Highly disrupted concordant sheets of leucogranite-pegmatite and biotite-hornblende granodiorite are abundant locally.

High-amplitude isoclinal folding of primary layering occurs in some outcrops but the metasedimentary paleosome otherwise shows no clear indication of the degree of finite strain. The granite pegmatite sheets, on the other hand, are generally highly boudinaged, and rolled in places. Thin granodiorite sheets commonly display intense quartz ribboning and local protomylonitic to mylonitic fabrics. Although no quantitative estimate can be given, it is concluded from this that the entire assemblage is highly strained. Typical highly strained feldspathoclastic "Guncoat" gneisses were observed in one locality, adjacent to the contact with the granodiorite.

Amphibolitic gneisses north of the metasediments on Keg Lake are mainly fine to very fine grained, finely laminated and strongly foliated to schistose. A prominent northeast-plunging stretching lineation is present. In one exposure, surfaces normal to lineation show flattened felsic and mafic clasts and, in other exposures, flattened pillow forms are apparent in down-plunge view. Minimum Y:Z shape fabric ratios of 50:1 were measured in places. In these cases, surfaces parallel to lineation (X-Z plane) generally display only a finely laminated fabric.

These observations suggest that the Keg Lake supracrustal rocks have suffered high finite strains consistent with, although not necessarily defining a continuation of, the Guncoat ductile thrust zone through this area.

b) Grand Rapids Section

We also examined exposures of the Keg Lake supracrustal belt along the north side of Grand Rapids.

This section mostly comprises mafic metavolcanic and probable subordinate mafic to ultramafic plutonic rocks displaying heterogeneous but generally severe strain. As in the northern part of central Keg Lake, most rocks are fine grained and strongly foliated amphibolitic gneisses and schists, which typically display transposed, foliation-parallel compositional banding and lamination on the millimetre to several centimetre scale. A widespread stretching lineation plunges steeply to the north or northeast. Subordinate metagabbro/metadiabase and tonalite-granodiorite sheets in the eastern part of the Grand Rapids section display heterogeneous strain with local development of protomylonitic to mylonitic fabrics.

Pillow Forms:

Flattened fragmental volcaniclastics and pillow lavas with selvages are recognizable in many places on surfaces normal to the stretch lineation. The pillow forms on these surfaces are typically small, rarely exceeding an area of about 100 cm^2 due to the extreme stretching. Selvages in are locally pitted, suggesting weathering-out of deformed amygdales, some of them quite large. Interpillow voids are also apparent in places, possibly due to the weathering-out of carbonate. This weathering has produced a characteristic "hackly" appearance on rock surfaces, even where there is considerable flattening, and may be a diagnostic feature to employ for the recognition of pillow lavas in poorly exposed outcrop. These features suggest that much of the sequence, particularly in the structurally higher eastern part, consists of pillowed flows.

Metavolcaniclastic Rocks:

Fine tectonic lamination of metavolcaniclastic rocks visible on surfaces parallel to lineation suggests extreme extension in the "X" finite elongation direction. Metre- to several metre-thick, coarse polymictic volcaniclastic units exposed just below the lower main rapids display well-defined flattened and strongly rodded felsic to mafic clasts. Here, X:Y shape fabric ratios of over 75:1 were recorded from some clasts, and may only be minimum values.

Possible Plutonic and Ultramafic Rocks:

The western and structurally lower part of the Grand Rapids section comprises inhomogeneously strained lensoid to streaky mafic and ultramafic gneisses, which may be mylonitized plutonic rather than metavolcanic rocks. The main rock-type is a fine-grained mafic schist with subordinate discontinuous, less-strained tectonic lenses or "foliation fish" of mottled medium-grained mafic gneiss, probably derived from metagabbro or metadiabase. This western sequence includes disrupted intercalations of black ultramafic gneiss, individually up to about 100 cm thick, which may represent metapyroxenite or ultramafic lava.

c) Conclusions

In summary, our observations suggest that the belt of metasediments and metavolcanics occurring through Keg Lake and Grand Rapids at the west end of Trade Lake is the locus of high ductile triaxial strains. Most rocks possess strong L-S fabrics with indications of high values of finite extension in the X (stretching lineation) direction. There is an abrupt strain gradation into less deformed granodiorite-tonalite on both sides, structurally below and above the belt. Although the type feldspathoblastic Guncoat Gneisses occurring to the west are hardly represented, our observations suggest that the strains demanded by the Guncoat nappe sole may be taken up in other rock units in this area.

3. Sadler Lake

This area was also investigated for any continuation of the regional-scale ductile shear zones presently manifested in the Guncoat Gneiss belt to the west. L-S tectonite fabrics examined in the area indicate only moderate degrees of finite strain, but extensional lineation and rodding is strongly manifested in places.

Shoreline rock exposures were examined at several places on Sadler Lake. The metasedimentary sequence in this area (unit 1 of Chakrabarti, 1968, 1969) was seen to include monotonous uniform medium- to fine-grained biotite-quartz-feldspar psammites and psammopelites ("biotite granulites"), which are locally interlayered on a several centimetre to metre scale with garnet or garnet-staurolite pelitic gneisses. Biotite and hornblende-biotite psammopelites were also observed, and contain interlayers and weathered out pocks of calc-silicate, and thin impure carbonate which in one cliff section forms up to 20 percent or more of the rock. A flaggy fissility parallel to foliation is a notable feature in all these rocks.

In the northeastern bay of Sadler Lake is a coarse staurolite-garnet schist which contains large balls of rodded quartz rock interpreted as highly deformed rootless quartz veins. Three structural features are apparent here: isoclinal folding, rodding/lineation, and crenulation folds which appear to be more or less contemporary with the growth of the staurolite. The isoclinal folding and lineation are coaxial, but the crenulation has deformed the rodding.

Several localities visited in the "hornblende gneiss" (unit 2 of Chakrabarti, 1968, 1969) show deformed mafic pillows. As in the Keg – Trade Lakes area, these pillows are highly rodded, recognizable only in down-plunge view, and in places show the same "hackly griking" due to weathering out of carbonate minerals. As elsewhere in the Glennie Domain (see also Slimmon, this volume), the small size of the pillows may be ascribed to extreme stretching in the X-direction. One exposure shows pillows averaging about 5 to 8 cm thick in the Z-direction and about 25 to 30 cm long in the Y-direction, although an exceptionally large pillow measured almost 20 by 60 cm. Accordingly, the pillows on Sadler Lake do not appear to be as flattened as those on Keg Lake. Quartz veins which transect some of the pillow structures have been folded in ptygmatic style with axial surfaces approximately parallel to the X-Y plane; these folds were presumably developed during the flattening process.

Some unusual rocks in the extreme eastern bay of Sadler Lake comprise paper-laminated ribbed quartzofeldspathic material alternating with carbonate layers. Although possibly ultramylonitic, some layers were found upon close inspection to contain small felsic fragments, and we concluded that the essential fabric of the rock was more influenced by original lithology (felsic to intermediate carbonate-rich tuffs) than by tectonic processes. More massive diopside-garnet gneiss containing thin layers, pods and lenses of garnet amphibolite, adjacent to this exposure, proved to be even more controversial.

Plutonic rocks (tonalite-granodiorite) along the southern margin of the Sadler Lake supracrustal belt are only weakly foliated, even as close to the margin as we could get. The band of pillowed rocks at the extreme northeastern end of the lake shows a number of contacts with granodiorite which vary from sharp-walled and undeformed to highly deformed with the granodiorite being strongly foliated.

a) Conclusions

Rocks in the Sadler Lake area display a prominent stretching lineation, but are generally much less flattened than the highly strained rocks seen on Keg and Trade Lakes. The continuation of the high-strain Guncoat Gneiss zone may lie to the north. As in the Keg – Trade Lakes area, the plutons bordering the supracrustal belt are very little strained close to the contact, and we conclude that they have acted as more rigid sheets, with strain concentrated in the supracrustal belt, where it is manifested mainly by the extensional lineation and rodding.

4. Lindstrom Lake

A half-day was spent in the northwest part of Lindstrom Lake, re-examining outcrops of a unit variously interpreted as metasedimentary biotite gneiss (Chakrabarti, 1969; Kirkland, 1976) and granitic gneiss (Kirkland, 1956).

Our observations support the view (Macdonald and Posehn, 1976) that this unit is indeed a variably deformed and relatively uniform, coarse-grained, slightly megacrystic biotite granite, which is locally cut by grey porphyritic and aplitic dykes. The rock generally varies from a coarsely augen-flasered gneiss to a finer grained more strongly foliated and lineated protomylonitic gneiss.

As previously noted by Macdonald and Posehn (op. cit.), one shoreline exposure displays spectacular heterogeneous strain features, with preservation of lensoid phacoids ("foliation fish") of less strained moderately foliated granite which are enveloped by more deformed gneiss. Well-defined transitional strain gradation occurs between the phacoids and the more highly strained matrix. Associated structures include tight to isoclinal folding of the folation and, in some outcrops, a later phase of kinking and strain-slip shear banding.

5. Oskikebuk and Wapawekka Lakes

One author (JFL) re-examined lakeshore outcrops on Oskikebuk Lake (Padgham, 1968) and across the central part of Wapawekka Lake (Padgham, 1966).

a) Oskikebuk Lake Section

Observations in the Oskikebuk Lake area suggest the following:

1) Most of Padgham's map unit 2 ("metasedimentary-metavolcanic rocks") comprises protomylonitic to mylonitic gneisses derived from plutonic rather than supracrustal protoliths. These include highly strained extensions of the main Oskikebuk Complex (largely a major pluton consisting of quartz diorite), granodiorite-granite bodies, and other fine-grained strained rocks possibly derived from plutons. Only a minor part of the unit is unequivocally derived from supracrustal rocks.
2) Padgham's units 7b and 7c (quartzofeldspathic gneisses) are protomylonitic to mylonitic equivalents of unit 8d (leucocratic granite gneiss). These units constitute a coherent, variably strained plutonic sheet.

The lateral discontinuity of rock units shown on Padgham's (1968) maps is interpreted largely as a function of strain variation rather than variation in protolith. Moreover, it is considered that a significant proportion of rocks previously identified as supracrustal on Padghams's maps are in fact deformed plutonic rocks. The belt of rocks lying south of the Oskikebuk Complex is thus interpreted as a broad north-dipping zone of heterogeneous ductile high strain underlying the complex, and is similar to the Alsmith Lake Zone (Delaney, this volume) overlying the northern margin of the complex.

b) Wapawekka Lake

Lakeshore outcrops were visited in the Churchman Island area on central Wapawekka Lake during two days, in an attempt to define possible western extensions of the Alsmith and Oskikebuk high-strain zones. Short traverses were also run north of the lake in order to determine the nature of the contact between the Folkerson Lake Granite and meta-arkoses/metaconglomerates (unit 3 of Padgham, 1966) to the south. Limited and generally poor outcrop rendered these efforts unsuccessful.

Most rocks in the area display a prominent, approximately down-dip stretching lineation similar in character to that documented in current mapping elsewhere in the southern part of the Glennie Domain (Delaney, Thomas, Slimmon this volume). The lineation is most clearly defined by preferred orientation of maximum finite extension axes of triaxially strained metaconglomerate clasts. Sparse outcrop data suggests that strain, as reflected in the character of both foliation and stretching lineation, increases towards the contact with the Folkerson Lake Granite, but no exposure was found within 100 m of the contact and its character was not determined. To the north, the granite is generally only weakly to moderately foliated.

Rocks in Padgham's (1966) map unit 2, south of the arkoses and conglomerates, are regularly and strongly foliated, fine-grained schists and gneisses, which possibly derive from supracrustal rocks. As no unequivocal strain indicators were observed, no well-defined high-strain zones could be documented.

6. Regional Comments

From a brief synthesis of the current remapping in the southern part of the Glennie Domain (Delaney, Thomas, Slimmon, this volume) and our own observations, we make the following comments on regional structural style and kinematic evolution in the Glennie Domain and Hanson Lake Block:

1) The southern part of the Glennie Domain appears to comprise a broadly homoclinal north-dipping stack of either predominantly supracrustal or plutonic sheets, typified by inhomogeneous internal strain and soled, in some cases at least, by ductile high-strain zones. Upright cross-folding on predominantly northeast-trending axes modifies this pattern only superficially on the regional scale.
2) Several hitherto unrecognized, although partly suspected, ductile high-strain zones are now documented in the Glennie Domain and the Hanson Lake Block. These are apparently related to early phases of structural evolution. Some appear to be of regional extent and kinematic significance, occurring as the sole to some of the regional thrust sheets. A ductile high-strain zone probably separates an Archean window (the Pelican Window) in the Hanson Lake Block from structurally overlying Early Proterozoic rocks.
3) Regional-scale heterogeneous ductile strain, related to early main phases of deformation, has masked the nature of the protoliths in many places, particularly where unequivocal finite strain indicators are lacking. Nevertheless, a significant proportion of rocks previously identified as, or implied to be derived from, supracrustal rocks are being re-identified as having plutonic protoliths. This has implications both for regional geotectonic interpretations and mineral exploration strategies.
4) Extensional lineation or rodding is prominent in much of the region, both as a component of intense L-S fabrics in localized ductile high-strain zones and more widely as the main element of weaker L-S fabrics or dominant constrictional strain L-fabrics in intervening rock packages. The pattern suggests significant regional strain partitioning during early tectonic evolution. There is also evidence in places for coaxiality of rodding with B-type fold axes, suggesting rotation of fold axes into the stretching direction. Such patterns are elsewhere characteristic of strain attending lateral flow during major ductile nappe emplacement.
5) Metamorphic grade generally increases to the north and west in the Glennie Domain, in the progression from lower to higher thrust sheets, implying large-scale metamorphic inversion. This is similar to the situation occurring across the "Kisseynew Front", where high-grade Kisseynew Gneisses structurally overlie low-grade rocks of the Flin Flon Domain. The metamorphic transition in the Glennie Domain is, however, less abrupt.

The above features appear to be broadly consistent with the view (Lewry et al., 1987, in press) that the Reindeer Zone, of which the Glennie Domain and Hanson Lake Block are parts, comprises a refolded stack of major nappe sheets and imbricated thrust wedges, possibly emplaced across an underthrust Archean continental crust, and perhaps representing an extension of the Superior Platform.

7. References

Ashton, K.E. (1987): Preliminary geological map of the Kisseynew Gneisses between the Sturgeon-Weir River and Kisseynew Lake, Saskatchewan; Geol. Surv. Can., Open File 1410.

Bell, K. and Macdonald, R. (1982): Geological calibration of the Precambrian Shield in Saskatchewan; *in* Summary of Investigations 1982, Sask. Geol. Surv., Misc. Rep. 82-4, p17-22

Bickford, M.E., Van Schmus, W.R., Collerson, K.D, and Macdonald, R. (1987): U-Pb zircon geochronology project: new results and interpretations; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p76-79.

Chakrabarti, A.K. (1968): Geology of the Trade Lake area (west half); Sask. Dep. Miner. Resour., Rep. 119.

Chakrabarti, A.K. (1969): Geology of the Trade Lake area (east half); Sask. Dep. Miner. Resour., Rep. 134.

Chiarenzelli, J.R., Lewry, J.F. and Landon, M. (1987): Bedrock geology, Iskwatikan Lake area: evidence for Hudsonian juxtaposition of Proterozoic and Archean rocks along a ductile detachment surface; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p46-51.

Coleman, L.C. (1970): Rb-Sr isochrons for some Precambrian rocks in the Hanson Lake area, Saskatchewan; Can. J. Earth Sci., v7, no2, p335-245

Kirkland, S.J.T. (1956): Geology of the Manawan Lake area (north half); Sask. Dep. Miner. Resour., Rep. 27.

Kirkland, S.J.T. (1976): Geology of the Manawan Lake area (south half); Sask. Dep. Miner. Resour., Rep. 175

Lewry, J.F. (1981): La Ronge Project: II. Geology of the Stanley shear zone; *in* Summary of Investigations 1981, Sask. Geol. Surv., Misc. Rep. 81-4, p28-33.

Lewry, J.F. and Slimmon, W.L. (1985): Compilation bedrock geology, Lac la Ronge, NTS area 73P/73I; Sask. Dep. Energy Mines, Rep. 225 (1:250,000 scale map with marginal notes).

Lewry, J.F., Thomas, D.J., Macdonald, R. and Chiarenzelli, J.R. (1987): Structural relations in accreted terranes of the Trans-Hudson Orogen: telescoping in a collisional regime?; *in* GAC-MAC Joint Annual Meeting, Saskatoon, Prog. Abstr., v12, p67.

Macdonald, R. (1974): Pelican Narrows (west) area; *in* Summary Report of Field Investigations by the Saskatchewan Geological Survey 1974; Sask. Dep. Miner. Resour., p30-37.

Macdonald, R. (1975): Semi-reconnaissance in three areas, Pelican Narrows area; *in* Summary Report of Field Investigations by the Saskatchewan Geological Survey 1975; Sask. Dep. Miner. Resour., p35-43.

Macdonald, R. (1981): Compilation bedrock geology, Pelican Narrows and Amisk Lake areas (NTS 63M, 63L, part of 63N and 63K); *in* Summary of Investigations 1981, Sask. Geol. Surv., Misc. Rep. 81-4, p16-23 (and accompanying 1:250,000 scale preliminary map).

Macdonald, R. and Posehn, G. (1976): Re-investigations in the Pickerel River and Limestone – Tulabi Lakes area; *in* Summary of Investigations by the Saskatchewan Geological Survey 1976; Sask. Dep. Miner. Resour., p44-52.

MacQuarrie, R.R. and Macdonald, R. (1978): Geological re-investigation mapping, Jan Lake area (part of NTS area 63M); *in* Summary of Investigations, Sask. Geol. Surv., Misc. Rep. 78-10, p16-25.

Padgham, W.A. (1966): Geology of the Wapawekka Narrows area (north half); Sask. Dep. Miner. Resourc., Rep. 103.

Padgham, W.A. (1968): Geology of the Deschambault Lake district; Sask. Dep. Miner. Resour., Rep. 114.

Sibbald, T.I.I. (1978): Geology of the Sandy Narrows (east) area; Sask. Dep. Miner. Resour., Rep. 170.

Project 8811

Mudjatik Domain, Geology and Gold Studies: Ithingo Lake[1]

C.T. Harper

Harper, C.T. (1988): Mudjatik Domain, geology and gold studies: Ithingo Lake; *in* Summary of Investigations 1988; Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

The discovery of significant gold values at Ithingo Lake, located 235 km northwest of La Ronge, has sparked interest in the Mudjatik Domain. Two areas were chosen for initial investigation: the area surrounding the Ithingo Lake discovery and Porter Lake (described separately). The primary objectives of the present investigations are to determine:

1) the nature and distinguishing characteristics of the enigmatic Mudjatik felsic gneisses, which have been considered to be basement to supracrustal rocks of the domain;
2) the stratigraphic, structural and metamorphic relations of the supracrustal belts, particularly the significance of iron formation in the sequence;
3) the tectonic setting, in order to explain the apparent spatial distribution of metasedimentary-dominated belts from metavolcanic-dominated belts; and
4) the geologic setting and controls on the gold mineralization in the Ithingo Lake area, which may be used to develop a model to further assist gold exploration in the Mudjatik Domain.

Approximately 150 km^2 surrounding Ithingo Lake, covering parts of NTS areas 74B-12, -13 and -14, were geologically mapped at 1:20,000 scale. This area is relatively rugged, with the major topographic features being controlled by bedrock structure. A portion of the Cree Lake recessional moraine crosses the southern part of the area. To the east and south, the area is bordered by broad expanses of muskeg and flat outwash plains. Access by float- or ski-equipped aircraft is available from La Ronge or Buffalo Narrows, 120 km southwest.

The Ithingo Lake area was previously mapped by Sproule (1938) and Sibbald (1973) at scales of 1:63,360 and 1:100,000, respectively. Mawdsley (1960) examined several aeromagnetic anomalies in the Ithingo Lake area and reported that they were caused by iron formation. Harper (1974, 1983) re-examined two of the magnetic anomalies south of Ithingo Lake as part of an investigation of iron occurrences in northern Saskatchewan.

1. General Geology

The Mudjatik Domain is one of several subdivisions of the Cree Lake Zone, a highly remobilized ensialic zone of the greater Trans-Hudson Orogen (Lewry et al., 1985). The domain is dominated by granitoid felsic gneisses of probable Archean age, which are considered to be basement to generally arcuate belts of supracrustal rocks of sedimentary and volcanic origin. The regional development of basin and dome structures in this domain has been interpreted as resulting from the interference of orthogonal fold axes superimposed upon earlier formed migmatite lobes (Lewry and Sibbald, 1977, 1980).

Supracrustal rocks at Ithingo Lake include psammitic to pelitic gneisses, quartzofeldspathic and amphibolitic gneisses of volcanic origin, and minor carbonates, calcsilicates, iron formation and metaperidotite sills. The formerly undifferentiated Mudjatik felsic gneisses are now subdivided into three units: 1) tonalitic gneiss, 2) layered 'felsic' gneisses of probable supracrustal origin and 3) a suite of porphyritic granites and granitic pegmatites. The tonalitic and layered felsic gneisses structurally underlie the supracrustals. The granites and pegmatites intrude all other rocks (Figure 1). The supracrustal rocks occupy major basinal structures, such as the Northeast Ithingo Basin, intervening cols and synformal keels between adjacent domal structures. Tonalitic gneisses tend to occur in the antiformal ridges between adjacent basins, whereas the major domal structures have granite cores. With the exception of the granites, the rocks were subjected to transitional granulite facies metamorphism.

2. Mudjatik Felsic Gneisses

a) Tonalitic Gneiss (T)

Tonalitic gneiss occurs mainly east of the Northeast Ithingo Basin (Figure 1). These white- to grey-weathering gneisses have a pronounced, very commonly swirly foliation defined by elongate, somewhat ovoid-shaped clots of biotite, which together with early, subparallel, white, anatectic granitoid neosome, outline small-scale refolded recumbent folds. Amphibolitic inclusions, ranging from a few centimetres to many tens of metres in size, are relatively common and locally form mappable zones. Irregular masses of generally unfoliated, white anatectic **leucogranodiorite** (subunit Tg), derived from the tonalitic gneiss, have invaded both tonalite and amphibolite. Contacts between the leucogranodiorite and host tonalite vary from diffuse to sharp. These leucogranodiorites are shown on the 1:20,000 scale map where they exceed 50 percent of the rock or occur in sufficiently large bodies.

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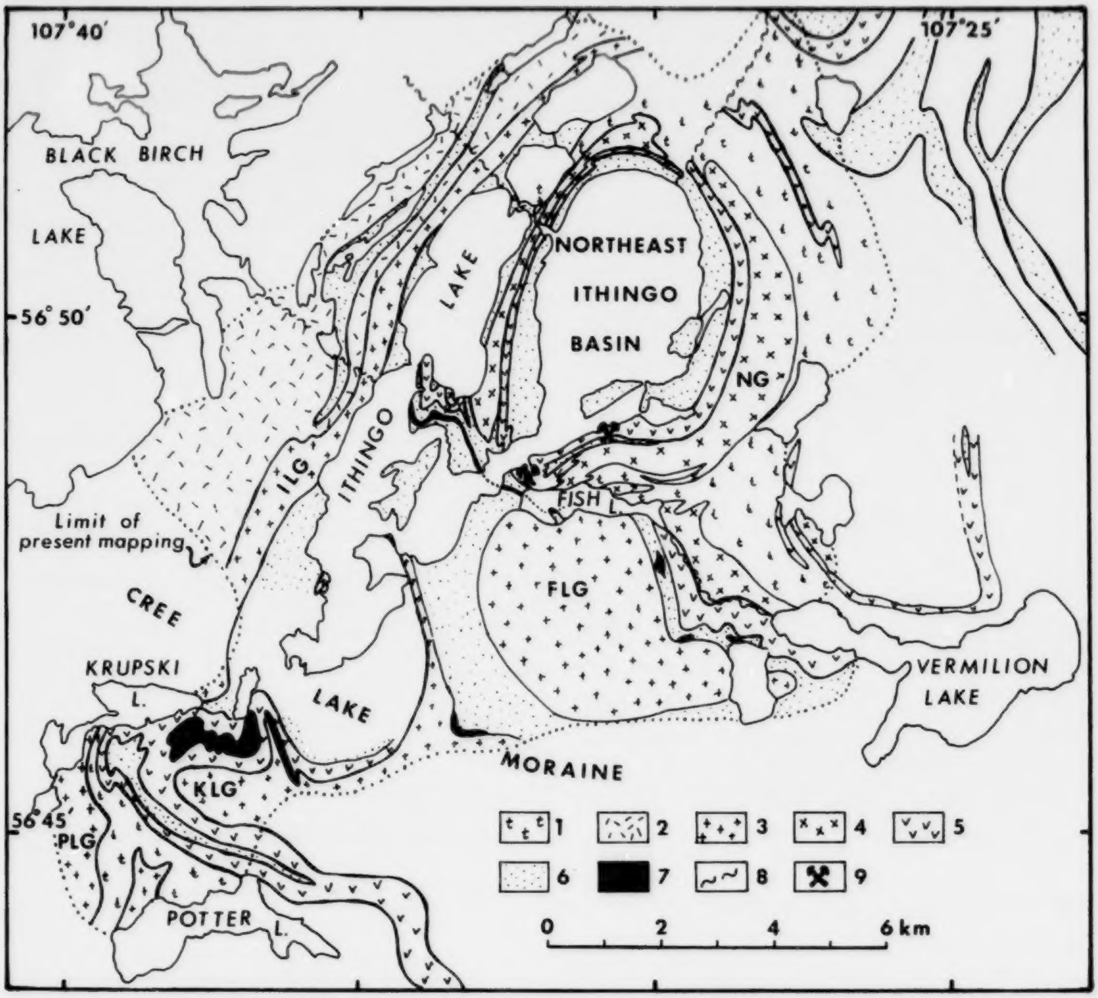
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Figure 1 - Geological sketch map of the Ithingo Lake area (modified from Sibbald, 1973). ILG, Ithingo Lake Granite; FLG, Fish Lake Granite; KLG, Krupski Lake Granite; PLG, Potter Lake Granite; and NG, Newmont Granite. 1, tonalitic gneiss; 2, layered felsic gneiss; 3, megacrystic augen granite; 4, porphyritic granite; 5, amphibolitic gneiss; 6, metasedimentary gneiss; 7, banded iron formation; 8, fault; 9, gold occurrence. Geology outside the limits of present mapping is from Sibbald (1973) and the unpatterned areas are dominantly undifferentiated Mudjatik felsic gneiss.

b) Layered Felsic Gneiss (F)

Layered felsic gneiss underlies much of the area west of Ithingo Lake (Figure 1). These rocks comprise alternations of generally fine-grained, equigranular granoblastic, pink and grey colour-banded biotitic quartzofeldspathic paleosome and pink coarser grained granitic to pegmatitic neosome. The colour banding reflects subtle to noticeable changes in the biotite content. Some of the more biotitic layers contain several percent garnet. Layers of the paleosome and neosome range from a few millimetres to a metre thick. Although these gneisses are granitic in composition, the fine even texture and layered character of the paleosome strongly suggest that it was derived from psammitic to psammopelitic protolith.

3. Ithingo Lake Supracrustals

a) Amphibolite (M) (mafic and intermediate metavolcanics)

The amphibolite unit is equivalent to Sibbald's (1973) mafic granulite unit, but because of the predominance of hornblende, the term amphibolite is used here. Recognition of primary volcanic features (pillows and pyroclastics) in a burned-over area south of Krupski

Lake confirms the volcanic origin of most of the amphibolitic gneisses. Amphibolites occur in belts up to 500 m wide encircling the northeastern basin of Ithingo Lake, on the western extension of the central peninsula of Ithingo Lake and along the west bank of Ithingo River from the east end of Fish Lake[1] to Vermilion Lake (Figure 1). South of Ithingo Lake, an arcuate, east-trending ridge is underlain by up to 300 m of amphibolite, which passes around a northerly-projecting cusp-shaped fold before turning abruptly south to southeast between Krupski and Potter Lakes. Thicknesses of up to 800 m, in part due to folding, are encountered in this area.

The amphibolites are rather heterogeneous, varying from thinly layered or streaky-looking types (probable metatuffs, metapyroclastics and thin flows) to thicker more massive types (probable flows, pillowed flows and or synvolcanic sills). They are light grey to black and fine to coarse grained, reflecting the compositional and textural changes common to volcanic rocks.

The amphibolites of the Northeast Ithingo Basin, and particularly those hosting the gold mineralization, are predominately thinly layered and of presumed tuffaceous origin. Flow types are less common. Apart from gross compositional layering and vague suggestions of pillow structures, no primary features could be positively identified in this area. In contrast, amphibolites along the Ithingo River and in the area between Krupski and Potter Lakes are more commonly of the flow type. The pillow structures identified south of Krupski Lake are folded and generally less than 50 cm long in cross-section but are highly stretched in the down-plunge direction. Pyroclasts are likewise highly rodded. Hypersthene is commonly present in the rocks between Krupski and Potter Lakes.

Amphibolitic gneiss of uncertain age and origin (subunit Ma) occurs as inclusions, layers and mappable zones in the tonalitic and layered felsic gneisses. Some of these amphibolites closely resemble the metavolcanic amphibolites described above, but it was not possible to demonstrate a genetic link. It is quite conceivable that several ages of amphibolitic rocks are involved, including: 1) older protolith from which the tonalitic gneiss may have been derived or into which it was intruded; 2) mafic dykes which are extremely boudinaged, folded and invaded by younger granodioritic anatectic melts; and 3) infolded keels of the metavolcanic-type amphibolites, which were subsequently intruded by the granodioritic neosome to produce large-scale agmatite.

b) Biotitic Amphibolite (Ab)

Biotitic amphibolite occupies an eye-shaped synform along the southeastern rim of the Northeast Ithingo Basin. The rocks are well layered and foliated, normally contain more biotite than hornblende, have abundant quartz-feldspar anatectic veins and lenses, and are interlayered with and grade into pelitic gneiss, which is locally garnet-bearing. The biotitic amphibolite gneiss is believed to be of sedimentary origin, derived from a greywacke protolith.

c) Quartzofeldspathic Gneiss (V) (felsic metavolcanics)

White- to light grey-weathering quartzofeldspathic gneiss occurs in several narrow lenses associated with unit M, most notably in the footwall of the Ithingo Lake gold showing as well as along the Ithingo River. These rocks generally contain a few percent biotite and/or hornblende and are interlayered with the adjacent amphibolites. The rather unusual feldspathic (mainly plagioclase) nature of these rocks suggests that they are derived from felsic metavolcanics of possible dacitic origin rather than from metasediments. A lens immediately west of Vermilion Lake, 30 to 80 m wide and at least 250 m long, contains **pyritic quartz-sericite schist** and **amphibolitic quartzofeldspathic gneiss**, which are interpreted to be sheared **metarhyolite** (subunit Vr) and **metadacite,** respectively.

South of Krupski Lake, a lens, measuring 20 to 50 m in thickness and at least 200 m in length, consists of massive and autobrecciated or agglomeratic **metarhyolite** (subunit Vr). Although folded, the angular shape of the feldspar phyric metarhyolite clasts is clearly evident in cross-sectional outcrop exposures, but they are strongly rodded as seen on dip surfaces. The clasts structurally overlie and grade downward with decreasing size into massive metarhyolite which contains faint streaky feldspar phenocrysts. Millimetre-size pale green diopside grains make up less than 3 percent of the rock. The textural evidence suggests that these rocks represent a small rhyolite dome complex. Another zone of felsic metapyroclastics occurs several hundred metres east.

d) Psammitic Gneiss and Quartzite (Q)

Psammitic gneiss and quartzite crop out around most of the Northeast Ithingo Basin and south of Krupski Lake. These rocks are generally well layered, ranging from several millimetres to a metre thick. Quartzitic layers are commonly separated by 3 to 10 mm thick biotitic layers, which may indicate a form of primary graded bedding. Feldspar is subordinate, and up to 10 percent in total of the following minerals may be present: biotite, cordierite, garnet, sillimanite (fibrolite) and magnetite. Blue to grey-blue cordierite occurs almost exclusively in anatectic granitic pods or lenses and may be accompanied by either garnet or sillimanite.

e) Psammopelitic Gneiss (S)

Psammopelitic gneisses contain from 10 to 25 percent of the dark minerals that occur in the psammitic gneisses, with which they are gradational.

f) Pelitic Gneiss (B)

Pelitic gneisses occur in the core of the Northeast Ithingo Basin, the elongate synformal keel west of Ithingo

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(1) ILcal name

Lake and as less prominent components in the other supracrustal belts. In places, they are intimately interlayered with and grade into psammopelitic gneisses. The pelitic gneisses are quartz-feldspar rocks containing greater than 25 percent of the same aluminous and ferromagnesian minerals that occur in the psammitic gneisses. Two distinctive subtypes are **garnet-sillimanite-biotite pelite** (subunit Bg) and **biotite-sillimanite pelite** (subunit Bs). Cordierite is present locally in the latter but rare in the former. Garnet porphyroblasts commonly attain several centimetres in diameter. A **graphitic-pyritic pelite** (subunit Bp) is commonly more siliceous than the other pelitic rocks, strongly iron stained and the cause of pronounced EM conductors.

g) Marble and Other Calcareous Rocks (C)

Discontinous bands of brown-weathering **marble** (subunit Cm) are scattered around Ithingo Lake. The most prominent is a 100 m wide band exposed along the west shore of Ithingo Lake. Calcite and dolomite are the principal constituents of the marbles, with variable amounts of forsterite, diopside, spinel, phlogopite and scapolite. In places, scapolite forms very coarse monomineralic layers up to 10 cm wide. Millimetre- to centimetre-thick layering, believed to be primary bedding, is preserved locally. A thin marble horizon south of Krupski Lake contains bright green apatite cystals up to 5 mm long.

Calcareous psammites and calc-silicate rocks (subunit Cc) are best developed south of Krupski Lake. They comprise distinctive thinly layered sequences of white siliceous layers alternating with green diopside-hornblende-rich layers. The mafic layers are commonly boudinaged, with some of the boudins possessing a core in which a relict, finely laminated texture is preserved. More thickly layered calc-silicate rocks are represented by equigranular quartz-diopside-plagioclase assemblages. Calcareous pods, which occur in psammitic gneiss, consist of diopside, plagioclase and minor biotite, hornblende and magnetite.

Rather ill-defined zones and pods of diopside, plagioclase, quartz, carbonate and hornblende occur in the amphibolitic gneisses. Some of these zones, which are accompanied by pyrite, pyrrhotite, chalcopyrite and galena mineralization, may represent metamorphosed alteration zones.

h) Banded Iron Formation (I)

Banded iron formation is best developed across the central part of Ithingo Lake and east of Krupski Lake (Figure 1). Intimate interlayering of oxide-, silicate- and sulphide-facies types of iron formation is typical. Quartz-rich layers 1 to 10 cm thick alternate with magnetite-rich layers, as well as with combinations of hornblende, diopside, garnet, biotite and magnetite and/or pyrite-pyrrhotite-rich layers of similar or lesser thickness. Associated with the iron formation are massive and typically **vuggy quartzites** of possible cherty origin (subunit Iq) which may contain up to 5 percent disseminated euhedral pyrite. Thin and generally unmappable silicate- and sulphide-facies iron formation horizons occur in the amphibolitic gneisses. The central Ithingo horizon occurs in a metasedimentary sequence, whereas the Krupski horizon occurs in metavolcanics. Regional structural synthesis and aeromagnetic patterns suggest that the two major iron formation horizons may be equivalent.

4. Intrusive Rocks

a) Ultramafic Intrusions (U)

A number of sill-like bodies of ultramafic rocks intrude the supracrustals, close to the margins of the amphibolitic gneiss (unit M). Three distinctive subunits are recognized: rusty-brown weathering, massive, magnetite-bearing **metaperidotite** (subunit Up); dark green, massive **hornblendite** (subunit Uh); and a white, green and brown layered rock of **anorthositic gabbroic, gabbroic and pyroxenitic** composition (subunit Ug). This latter body is closely associated with metaperidotite near the mouth of Dragonhead Bay[1].

b) Granite and Granite Gneiss (G)

Granite and granite gneiss underlie about 30 percent of the area in a number of large discrete bodies and smaller lenses. As a group, they are pink weathering, porphyritic to megacrystic, vary from massive to strongly foliated and are compositionally homogeneous with only slightly less biotite in their cores. They are clearly intrusive into all other rocks and, although they do not appear to have the same metamorphic history as the other rocks, they have undergone regional deformation. Two major varieties, which may actually represent a continuum, are recognized: **megacrystic augen granite** (subunit Gm) and **porphyritic granite** (subunit Gp).

Megacrystic augen granite (subunit Gm) occurs in several large bodies, the Fish Lake[1], Krupski Lake and Potter Lake Granites, and in the Ithingo Lake Granite, an elongate sill-like body along the western shore of Ithingo Lake. Augen-shaped potassium feldspar megacrysts up to 4 cm long are characteristic of these rocks. The augen texture is most strongly developed along the margins of the 'stocks' and is less intense in the cores. A supracrustal-rich zone up to 100 m wide also occurs near the margin of these bodies. The strong augen texture, narrow width and linearity of the Ithingo Lake Granite suggest that it was emplaced along a fault similar to the Junction Granite southwest of Careen Lake (Sibbald, 1974; Lewry, 1974).

Porphyritic granite (subunit Gp) occurs in smaller sill-like bodies, particularly around the Northeast Ithingo Basin and along the Ithingo River. These rocks are typically massive to weakly foliated, although the Newmont Granite has well-developed augen texture along the western margin of the north-trending part of that body.

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(1) Local name

Potassium feldspar phenocrysts rarely exceed 1 cm in length in this unit and biotite generally comprises less than 5 percent, indicative of a leucogranite composition. Sharp intrusive contacts were observed in many places, but they are especially well exposed along the north shore of Fish Lake[1] and the central peninsula of Ithingo Lake.

c) Pegmatite (P)

Both granite types contain and grade into irregular masses and ill-defined veins of pink pegmatite; this indicates a genetic link between them. Generally, the pegmatites intrude all other rocks as sharp-walled veins and dykes up to 30 m wide. Like the granites, they have been deformed, having undergone open folding and have been boudinaged. They have a simple mineral composition consisting of quartz, potash feldspar and subordinate plagioclase, with minor biotite, muscovite and magnetite. Magnetite locally constitutes up to 30 percent of the rock, perhaps due to contamination from iron formation such as along the northern contact of the Fish Lake Granite, 1.5 km west of Vermilion Lake.

5. Structure

The Ithingo Lake area has undergone polyphase deformation, resulting in the present dome-and-basin configuration. Apart from the gross and locally fine lithological layering considered to be bedding, primary sedimentary and volcanic structures are rare. The pillow structures south of Krupski Lake are too strongly deformed to indicate flow top directions.

Lewry and Sibbald (1977, 1980) invoked an early phase of regional recumbent migmatite lobe formation (D_1) followed by superposition of nearly orthogonal, upright folds about west-northwest- (D_2) and north-northeast-trending axes (D_3). Sibbald (1973) indicated that the earliest recognizable deformation (i.e., migmatite lobe formation) produced the regional penetrative foliation, which is generally parallel to the lithological layering and to axial planes of small-scale intrafolial isoclinal folds. The present author supports Sibbald's interpretation but suggests that the foliation is mimetic of an earlier fabric that preceded the migmatite lobe formation and transitional granulite facies metamorphism. Mineral lineation and the stretching direction of pillows and volcanic clasts were formed during D_1. Large-scale D_1 folds are difficult to recognize, but may be represented by synformal folds in the Krupski Lake area.

The subsequent orthogonal fold events fold the foliation, refold the earlier folds and produce, in addition to the dome-and-basin interference pattern, small-scale open upright folds. There is little evidence of an axial planar fabric associated with D_2, the west-northwest fold event. A locally well-developed fracture cleavage is associated with the north-northeast D_3 folding. The resultant dome-and-basin structures are doubly plunging along the major fold axes but locally, as along the east side of the Northeast Ithingo Basin, can be vertical to slightly overturned.

Structurally controlled, foliation-parallel, folded, boudinaged and metamorphosed quartz vein systems in the supracrustals indicate a very early period of shearing, which predates peak metamorphism. The more obvious faults in the area are steeply dipping to subvertical and are roughly parallel to the directions of orthogonal folding. Sinistral movement is typical of the west-northwest-trending faults, whereas dextral movement is characteristic of the younger north-northeast faults. The development of augen textures in the granites suggests that a strong shear component either accompanied or directly succeeded their emplacement.

6. Metamorphism

Metamorphic mineral assemblages in the supracrustal rocks indicate that uppermost amphibolite – transitional granulite facies conditions were attained in the Ithingo Lake area. Minerals indicative of the peak conditions are preserved in the rocks south of Krupski Lake, where hypersthene is a major constituent in some of the mafic metavolcanics. In the Northeast Ithingo Basin, hypersthene is rare and tends to be restricted to calc-silicate pods and to some of the ultramafic lenses. The various garnet-cordierite-sillimanite assemblages of the pelitic gneisses are characteristic of the low-pressure transitional granulite facies. The fact that primary volcanic features have survived granulite facies metamorphism implies that peak conditions must have occurred during a static interval, outlasting the D_1 deformational event. Retrograde metamorphism appears to have been minimal.

Although the granites and pink pegmatites show some recrystallization, they do not appear to have undergone the same high grade of metamorphism as the supracrustals.

7. Economic Geology

In his report on the Mudjatik area, Sproule (1938) indicated that the region between Vermilion and Black Birch Lakes was the most favourable for prospecting. He reported the occurrence of trace quantities of gold associated with sulphide mineralization (pyrite, pyrrhotite, arsenopyrite, chalcopyrite, sphalerite and magnetite) in metavolcanic-hosted quartz veins and in rusty, silicified metavolcanics. He indicated four areas of interest:
1) along the south shore of Vermilion Lake, 2) further west along the same volcanic belt, 3) along the central peninsula of Ithingo Lake, and 4) south of Ithingo Lake where the massive quartzites were thought to be large quartz veins. Unfortunately, none of these locations were indicated on his map. The central peninsula was staked at the time of Sproule's visit, but there is no other record of work performed on the claims.

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(1) Local name

Perhaps of indirect importance to the Ithingo Lake area was a report made by Mawdsley (1931) of a platinum placer staking rush in the Spear River area, approximately 35 km to the southwest. He stated that small quantities of platinum-bearing material were found in boulder-rich gravels, but was unsure of potential ultramafic source rocks in that area. Such rocks occur in the Ithingo Lake area and in other supracrustal belts northeast and east-northeast of the Spear River.

Reports of banded iron formation being found in the Mudjatik region prompted the Saskatchewan Department of Mineral Resources to carry out an airborne magnetic survey over part of the region in 1954 (Mawdsley, 1960). Ground checking of the better anomalies, including two south of Ithingo Lake, was completed by Mawsdley (ibid.) in 1956. He concluded that the iron formation exposed near Krupski Lake was not, at that time, of economic importance. Between 1957 and 1960, this same area was prospected and numerous trenches were excavated in the iron formation in an apparently unsuccessful search for gold mineralization. During a period of widespread uranium exploration in the late sixties, the massive quartzites were again sampled, yielding trace gold and up to 0.26 oz./ton Ag (Assessment File 74B-13-0003, Saskatchewan Energy and Mines, Regina). Apart from the author's examination of the iron formations in 1974 (Harper, 1974), the Ithingo Lake area has lain virtually dormant until the present surge of gold exploration activity, sparked by the announcement of a new gold discovery by Claude Resources Inc. at Ithingo Lake (Northern Miner, 1987).

Initial reports by Claude Resources indicated gold values of 0.16 and 0.3 oz./ton over widths of 6.1 and 2.7 m, respectively, from trenches excavated in an apparently stratabound zone in metavolcanics and metasediments (Northern Miner, 1987). Grab samples from parallel zones yielded up to 0.88 oz./ton Au. Claude Resources has since joint-ventured the property with Newmont Mines, who have taken over as operator. Additional stripping and sampling by Newmont have confirmed the earlier results. The results from an initial diamond-drill program have yet to be released (Northern Miner, 1988).

The gold mineralization occurs in an east-trending, steep northerly-dipping, foliation-parallel quartz-filled shear in amphibolitic gneiss (interpreted as mafic metavolcanics) along the southern rim of the Northeast Ithingo Basin. The quartz vein system has been isoclinally folded, boudinaged and metamorphosed, indicating that it and the mineralization predate the major deformation and peak metamorphism. Disseminated pyrite, pyrrhotite and arsenopyrite occur scantily in the veins and, although not always obviously visible, also occur in the structural hanging wall. Strong iron stain pervades the hanging wall rocks but is negligible in footwall rocks. The mineralized zone, which has has been traced for about 340 m (Northern Miner, 1988), lies a metre or two 'above' the contact with the quartzofeldspathic gneiss suspected of being felsic metavolcanics. Thin layers, up to 30 cm thick, of coarse-grained garnet, hornblende, diopside, quartz and magnetite, considered to be silicate-facies iron formation, occur in close proximity to the mineralized zone, but their relationship to the gold mineralization is uncertain. It is believed that genesis of the gold mineralization is similar to many other structurally controlled quartz vein type gold deposits hosted in greenstone belts.

Similar foliation-parallel quartz vein systems and silicified zones in rusty-weathering amphibolitic gneiss occur along the central peninsula, along the Ithingo River extending easterly to and along the south shore of Vermilion Lake, and in the area east and south of Krupski Lake. One such quartz vein exposed in a cliff face on the east shore, near the south end of the central peninsula, contains disseminated pyrite and cross-fractures mineralized with pyrite, chalcopyrite and malachite. Grab samples of the vein and unmineralized wall rocks, collected by the author, gave the following values:

	ppb	*ppm*			
Sample No.	*Au*	*Ag*	*As*	*Cu*	*Zn*
8811-2017 amphibolite	13	0.9	68	13	20
8811-2018 quartz vein	20	3.0	<50	1845	37
8811-2019 quartz vein	9	0.8	<50	395	11

Calc-silicate pods and lenses in the amphibolitic gneisses (unit M) locally contain disseminated pyrite, pyrrhotite, chalcopyrite and minor galena. A grab sample (8811-108) of this type of mineralization, collected north of the Claude Resources gold discovery, contains 8822 ppm Cu, 2580 ppb Au, 18.7 ppm Ag and 63 ppm As.

Ten grab samples were collected from the large area of iron formation east of Krupski Lake. Only one of these, 8811-2007 (a magnetite-rich sample), gave significant results at 478 ppb Au, 2.2 ppm Ag and 430 ppm As. A grab sample of garnetiferous oxide-silicate facies iron formation (8811-1008) from the band that crosses the central part of Ithingo Lake gave 205 ppb Au on analysis.

The discovery of significant concentrations of gold in the supracrustal rocks of the Mudjatik Domain illustrates the potential for mineral deposits to survive in these high-grade terrains. We are reminded that some world-class mineral deposits, the Broken Hill Pb-Zn deposit for example, occur in Early Precambrian granulite facies terrains (see Katz, 1988).

8. References

Harper, C.T. (1974): Iron ore evaluation; *in* Summary Report of Field Investigations by the Saskatchewan Geological Survey 1974; Sask. Dep. Miner. Resour., p78-83.

__________ (1983): Iron ores of northern Saskatchewan; Sask Energy Mines, Rep. 220, 102p.

Katz, M.B. (1988): Metallogeny of Early Precambrian granulite facies terrains; Precambrian Res., v39, p77-84.

Lewry, J.F. (1974): La Loche (north) area: summary of structural geology; *in* Summary Report of Field Investigations by the Saskatchewan Geological Survey 1974; Sask. Dep. Miner. Resour., p46-55.

Lewry, J.F. and Sibbald, T.I.I. (1977): Variation in lithology and tectonometamorphic relationships in the Precambrian basement of northern Saskatchewan; Can. J. Earth Sci., v14, p1453-1467.

_________ (1980): Thermotectonic evolution of the Churchill Province in northern Saskatchewan; Tectonophysics, v68, p45-82.

Lewry, J.F., Sibbald, T.I.I. and Schledewitz, D.C.P. (1985): Variation in character of Archean rocks in the western Churchill Province and its significance; *in* Ayres, L.D., Thurston, P.C., Card, K.D. and Weber, W. (eds.), Evolution of Archean Supracrustal Sequences; Geol. Assoc. Can., Spec. Pap. 28, p239-261.

Mawdsley, J.B. (1931): Mineral possibilities in northern Saskatchewan with special reference to areas reconnaissanced in 1931; Sask. Dep. Miner. Resour., unpub. rep., 26p.

_________ (1960): Iron ore occurrences, northwestern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 50, 19p.

Northern Miner (1987): New gold find for Claude Res.; Northern Miner, Nov. 16, 1987, pA2.

_________ (1988): Newmont drilling at Claude's Ithingo; Northern Miner, Sept. 19, 1988, p20.

Sibbald, T.I.I. (1973): 74-B-NW: Mudjatik (NW); *in* Summary Report of Geological Investigations Conducted in the Precambrian Area of Saskatchewan 1973; Sask. Dep. Miner. Resour., p35-42.

_________ (1974): La Loche (north) area: reconnaissance geological survey of 74C-NW and 74C-NE; *in* Summary Report of Field Invetigations by the Saskatchewan Geological Survey 1974; Sask. Dep. Miner. Resour., p38-45.

Sproule, J.C. (1938): Mudjatik area, Saskatchewan; Geol. Surv. Can., Pap. 38-8, 13p.

Project 8811

Mudjatik Domain, Geology and Gold Studies: Porter Lake Area[1]

C.T. Harper

Harper, C.T. (1988): Mudjatik Domain, geology and gold studies: Porter Lake area; *in* Summary of Investigations 1988; Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

Porter Lake, 85 km northeast of Buffalo Narrows, is surrounded by rugged rocky terrain and provides excellent transects through the felsic gneisses of the Mudjatik Domain as well as access to a number of supracrustal belts. In view of the knowledge gained at Ithingo Lake (Harper, this volume), field investigations in this area were more of a fact-finding nature. Once major lithological differences had been identified in the felsic gneisses, selected areas were chosen for closer scrutiny. The widest sections of supracrustal belts were examined because of the greater potential for primary sedimentary and/or volcanic features being preserved.

1. General Geology

The Mudjatik Domain is composed mainly of granitoid felsic gneisses of probable Archean age (hereafter referred to as the Mudjatik felsic gneisses), which are considered to be basement to narrow, arcuate to closed belts of supracrustal rocks of sedimentary and volcanic origins. Polyphase deformation has produced dome-and-basin structures, and accompanying metamorphism attained granulite facies conditions over large parts of the domain (Pearson, 1977; Pearson and Lewry, 1974; Lewry and Sibbald, 1977). In the Porter Lake area, Alcock (1935) and Pearson (1977) described the Mudjatik felsic gneisses as a highly variable group of rocks, and left them as undifferentiated on their maps. Sibbald (1975), during detailed geological mapping around areas of anomalous radioactivity at the north end of Blackstone Lake and at Porter Lake, identified four subdivisions of the felsic gneisses, including pegmatite, granite, granite gneiss and augen granite gneiss. The present author has subdivided the Mudjatik felsic gneisses around Porter Lake into three units: 1) tonalitic gneiss, 2) generally layered felsic gneiss of probable supracrustal origin, and 3) granite and granite pegmatite. These subdivisions are essentially the same as those identified at Ithingo Lake (Harper, this volume).

Supracrustal rocks at Porter Lake also include the same types as at Ithingo Lake: psammitic to pelitic gneiss, iron formation, hypersthene-bearing mafic granulites (mafic metavolcanics), and minor quartzofeldspathic gneiss (interpreted as felsic metavolcanics). Ultramafic intrusions are more common than at Ithingo Lake.

2. Mudjatik Felsic Gneisses

a) Tonalitic Gneiss

At Porter Lake, the tonalitic gneiss is typically grey, coarse grained and has a well-developed swirly foliation, much the same as tonalitic gneiss at Ithingo Lake. In the core of the Barker Bay Dome (Figure 1) and in other areas at the north end of Porter Lake, the tonalitic gneiss weathers yellowish-brown and locally contains hypersthene as well as resinous brownish or greyish-green plagioclase, features which are indicative of granulite facies metamorphism.

Along the west shore of the central part of Porter Lake, the tonalitic gneisses are white to grey weathering, lack hypersthene and display a transition from strongly foliated to unfoliated. Also in this area, several different phases are distinguishable based upon grain size and mineralogical variations as well as crosscutting relationships. An early **fine-grained dioritic phase** occurs as scattered rafts and blocks in the typical coarse-grained well-foliated tonalite. Both types are intruded by a weakly foliated to massive **anatectic leucogranodiorite**, which creates a large scale-agmatite. The leucogranodiorite also intrudes large enclaves of amphibolitic gneiss engulfed in the tonalitic gneiss.

The tonalitic gneiss complex is intruded in a few places by mafic to intermediate dykes, the latter being compositionally similar to the tonalite. Younger aplitic to pegmatitic dykes cut all of the above. All the dykes have undergone some deformation, but the mafic dykes are the most deformed.

On several islands and the mainland in south-central Porter Lake is a body of weakly foliated **biotite-hornblende tonalite–quartz diorite** that appears to be less deformed and of lower metamorphic grade than the rest of the tonalitic gneisses. The relatively undeformed state of this body suggests that it may be a younger phase of the tonalitic rocks.

The mineralogical differences observed in tonalitic gneisses at Porter Lake are probably a function of the present erosion surface exposing different structural levels and crossing metamorphic isograds such that higher metamorphic grades are progressively exposed in the cores of stuctural domes. The compositional and textural features of the tonalitic gneisses suggests that they are mainly of plutonic origin.

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(1) Project funded under the Saskatchewan component of the Canada–Saskatchewan Subsidiary Agreement on Mineral Development 1984–89

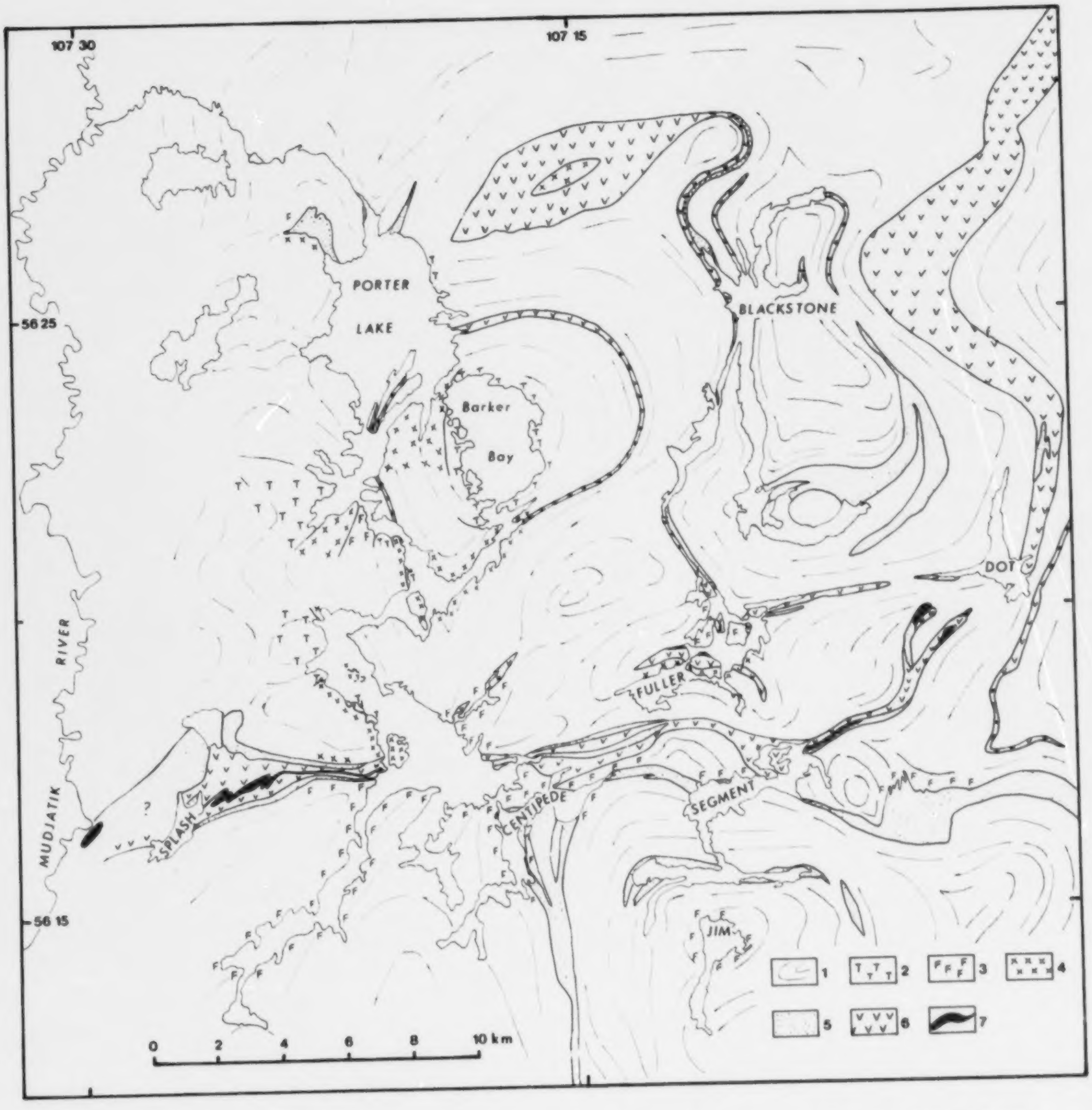

Figure 1 – Geological sketch map of the Porter Lake area (modified from Pearson, 1977). 1, undifferentiated Mudjatik felsic gneiss. Units 2 to 4 are the authors' subdivisions: 2, tonalitic gneiss; 3, layered felsic gneiss; 4, granite, leucogranite. 5, metasedimentary gneiss; 6, mafic granulites and ultramafic intrusions; 7, banded iron formation.

b) Layered Felsic Gneiss

Layered felsic gneisses commonly border and apparently underlie the supracrustal belts. As at Ithingo Lake, the layered felsic gneisses have two main components, a **supracrustal paleosome** and a **granitic neosome**. The paleosome is a pink to grey, colour banded and layered, generally fine-grained, equigranular, granoblastic biotitic quartz-feldspar rock of probable psammitic to psammopelitic origin. The paleosome has undergone local as well as extensive anatexis, yielding a coarser grained equigranular massive to weakly foliated leucogranite neosome, which occurs as *lit-par-lit* veins and ill-defined masses. Larger masses commonly contain relict inclusions of the paleosome. Where hypersthene accompanies biotite (as at Jim Lake), the gneisses weather yellowish brown and have a rather greasy appearance.

c) Granite and Granite Pegmatite

Granite and granite pegmatite are the youngest members of the Mudjatik felsic gneisses. The pink to red weathering **granite** varies from fine to coarse to porphyritic, is typically massive to weakly foliated, but has augen texture developed locally and is composed mainly of distinctive grey to black quartz and pink potassium feldspar with only minor biotite and plagioclase. In places, these granites have sharp contacts with the tonalitic and felsic gneisses, appearing to 'overlie' them and also to have been involved in the dome-and-basin forming events. This relationship might be explained if the granites were emplaced as sheet-like bodies into the migmatite nappe lobes, before the dome-and-basin folding. Elsewhere, the granites have gradational contacts with both tonalitic and layered felsic gneisses. The transition of tonalitic gneiss into granite is marked by a progressive increase of potassium feldspar, possibly by metasomatic replacement of plagioclase and loss of the gneissic textures. Transition from layered felsic gneiss into a homogeneous, coarse-grained to porphyritic leucogranite is characterized by the progressive increase of neosomal granite to the complete exclusion of supracrustal relicts.

Porphyritic granite intrusions were found in several areas during the present investigations. These include: 1) an eye-shaped body, approximately 2 km long by 0.5 km wide, that occurs in the centre of the ovoid-shaped area of mafic granulites east of the north end of Porter Lake; 2) a 1 km long body that intrudes the weakly deformed tonalite found in south-central Porter Lake; and 3) an elongate body, at least 3 km long and 0.5 km wide, that occurs along the northern margin of the supracrustal belt between Splash and Porter Lakes (Figure 1).

Pink granite pegmatite intrudes all rocks at Porter Lake. It also occurs as poorly defined veins in the granite, suggesting that it is the last phase related to the formation of the granite. On the west shore of Porter Lake and parallel to the northern margin of the east-west supracrustal belt (Figure 1) is a zone, up to 100 m wide, in which a swarm of pegmatite dykes intrudes both supracrustals and adjacent 'felsic' gneisses. Some of the dykes are folded, indicating that they were emplaced prior to at least the last deformation. Farther west near Splash Lake, several large pegmatites, which intrude mafic granulites and iron formation, are parallel to a north-northeast-trending axial planar fracture cleavage related to the last phase of dome-and-basin folding.

3. Supracrustal Rocks

Supracrustal rocks at Porter Lake are consistently of higher metamorphic grade than supracrustals at Ithingo Lake. At Porter Lake, hypersthene is a common constituent, but apart from gross lithological layering and quartz-magnetite banding in iron formation being considered as original bedding, primary sedimentary and volcanic features have not been positively identified. Because the supracrustal rocks at Porter Lake are essentially the same as at Ithingo Lake, only some significant observations will be included here.

a) Quartzite

On the west shore of Centipede Lake, about 500 m south of the creek that flows into Porter Lake (Figure 1), is a small synformal keel, about 70 m long by 15 m wide, of massive to weakly foliated, blue-grey **quartzite** that appears to rest unconformably on layered (psammitic) felsic gneiss. At the northwest end of this structure, layering/foliation in the underlying felsic gneiss is perpendicular to the foliation evident in the quartzite. Along the east side of the quartzite keel, the respective foliations are divergent. Farther along on the north shore of Centipede Lake is another area of quartzite which contains thin interlayers of meta-arkose. Layering/foliation in the quartzite is again divergent from that of the layered (psammitic – psammopelitic) felsic gneiss which crops out a little further inland.

b) Iron Formation and Associated Rocks

An area designated as psammitic gneiss (unit Q of Pearson, 1977) on the north shore of the large island near the middle of Fuller Lake is interpreted by the author to be **felsic metavolcanic rock**. Associated with these rocks and separating them from mafic granulites are strongly iron-stained **siliceous sulphide-facies iron formation**. Similar rocks occur along strike both west and north of the island, but they are not indicated on Pearson's map. **Oxide facies iron formation** is also present in this zone.

Iron formation is generally much more widespread than indicated on Pearson's (1977) map. One horizon can be traced intermittently for nearly 30 km from near the Mudjatik River east to Dot Lake. Traverses across the supracrustal belt between Splash and Porter Lakes revealed a continuous layer of iron formation, which occurs within a sequence of mafic granulites (mafic metavolcanics) and is closely associated with ultramafic intrusions (Figure 1). **Banded quartz magnetite** is the dominant facies, but in places **magnetite-poor quartzitic facies** (metachert) dominates. Most magnetite-rich bands are less than 3 cm thick, but a spectacular 3 m wide band of massive magnetite was found on the west side of a small lake midway between Splash and Porter Lakes. In several places along this belt, folding has thickened the iron formation unit to as much as 300 m in width.

4. Ultramafic Intrusions

As with the iron formations, ultramafic intrusions were found to be more abundant than indicated on the previous geological maps, occurring almost exclusively in the mafic granulite belts and very commonly intimately associated with iron formation. A series of pods and lenses, perhaps the remnants of a once-continuous band of ultramafic rocks, can be traced for at least 16 km along the southern margin of the supracrustal belt from west of Splash Lake to a point about 2 km east of Porter Lake. Similar rocks are known to occur farther east along this same belt. Most of the ultramafics appear to be **metaperidotites**, but **metapyroxenites** also exist as individual pods or more commonly as layers up to 30 cm thick in the metaperidotite. Magnetite is normally abundant and sulphides are present locally.

5. Economic Geology

Alcock (1935) reported that a number of small groups of claims had been staked in the Porter Lake region in the early thirties, mainly covering quartzitic material and apparently as gold prospects. Grab samples collected by Alcock gave negative results for both gold and silver. Very limited mineral exploration was carried out in the Porter Lake area until the period between 1967 and 1977 when large areas were prospected for uranium, base and precious metals and iron. The discovery of significant gold values at Ithingo Lake has refocussed exploration activty on gold.

a) Gold and Silver

Trace amounts of gold (generally less than 0.04 oz./ton) have been reported from grab samples of gossanous mafic granulites and ultramafic rocks that contain disseminated sulphides (mostly pyrite, pyrrhotite and chalcopyrite). Silver values in these samples were typically ten to twenty times the gold concentration and similar values have also been reported from banded quartz-magnetite iron formation (Saskatchewan Mineral Deposit Index for 74B-6).

Prospective targets for gold mineralization in the Porter Lake area are still to be found in the mafic granulites, ultramafic rocks and iron formation, particularly where disseminated sulphides are present. Associated silicification and/or quartz veining would enhance the potential for finding elevated gold concentrations.

b) Base Metals

Disseminated to semimassive sulphide mineralization is normally found in the mafic granulites and ultramafic rocks throughout the region, and locally may contain up to several percent copper with lesser nickel and typically low concentrations of zinc, lead, gold and silver (Saskatchewan Mineral Deposit Index for NTS area 74B-6). An example of this type of mineralization is a grab sample of metapyroxenite containing disseminated pyrite, pyrrhotite and chalcopyrite, collected by the author from an island near the east shore of south central Porter Lake. This sample contains 1703 ppm Cu, 434 ppm Ni, 2.1 ppm Ag, 119 ppb Au, 18 ppm Zn and <10 ppm Pb.

At the east end of Segment Lake, a sediment-hosted base metal occurrence, consisting of disseminated galena, pyrite and pyrrhotite in feldspathic metapsammite, contains up to 2.4 percent Pb, 0.08 percent Zn and 0.4 oz./ton Ag (Pearson, 1977).

c) Iron

As mentioned above, banded quartz-magnetite iron formation can be traced intermittently for about 30 km from the Mudjatik River east to Dot Lake. Several high magnetic anomalies associated with this band have been investigated in the past to determine their economic potential (e.g., Mawdsley, 1960; Harper, 1983). The magnetic anomalies occur in areas where the iron formation has been tightly folded to produce greater thickness, but the size and grade have not warranted exploitation under existing economic conditions. In view of the world-wide association of gold deposits hosted in iron formation, iron formations of the Mudjatik Domain represent a virtually untested exploration target.

d) Uranium

Two types of uranium mineralization have been recognized in the area; 1) occurrences in remobilized basement and 2) occurrences in supracrustals (Sibbald, 1975; Sibbald et al., 1977). Radioactive occurrences in the remobilized basement are caused by uraninite and secondary uranium bloom in the weakly foliated pink granites, leucogranites and granite pegmatites, all of which are believed to be the anatectic fraction derived from the Mudjatik felsic gneisses. Radioactive occurrences in supracrustal rocks in the Porter Lake area belong primarily to a pelite-pegmatite type (Sibbald et al., 1977). Uraninite and secondary uranium bloom occur in white anatectic segregation pegmatites derived from the host graphitic pelitic gneisses. Sulphide mineralization, including pyrite, molybdenite and chalcopyrite, is commonly associated with this type. To date, no economic concentrations of uranium have been found.

6. Discussion

Sibbald et al. (1977) proposed that the supracrustal rock sequences of the Cree Lake Zone are most consistent with deposition on a relatively stable, shallow marine to subaerial continental platform. Harper (1983) reiterated this idea and described a general stratigraphic sequence involving an early period of clastic sedimentation followed by widespread extrusion of mafic volcanics accompanied by local sedimentation, intrusion of ultramafic rocks and precipitation of iron formation. This was in turn followed by further deposition of clastic sediments, carbonates and more iron formation. Harper indicated that this succession was similar to other well-known Precambrian iron-bearing areas, for example the Limpopo mobile belt of southern Africa, the Krivoy Rog area of U.S.S.R. and the Hammersley Group of Western Australia.

The present investigations confirm this general model, but have also shown that volcanism was locally bimodal (i.e., basalt–rhyolite) and, in some areas such as Ithingo Lake, intermediate volcanics were also extruded. Across the Mudjatik Domain, the mafic granulites have great lateral extent, but are commonly of limited thickness (generally several hundred metres) compared to typical greenstone belts. It is suggested here that incipient continental rifting may have been responsible for localization of the volcanic sequences and could also have provided the linear loci for intrusion of ultramafic rocks, such as seen in the Porter Lake area.

A striking similarity to the Mudjatik Domain is found in the association of iron formation with both metabasaltic and clastic metasediments in the Southern Margin Zone of the Damara Orogen in Namibia (Breitkopf, 1988). Breitkopf states that the mafic rocks are equivalent to continental within-plate tholeiitic basalts, probably derived from lithospheric material during crustal extension and thinning. On the basis of their great lateral extent and limited thickness (generally <30 to 40 m) Breitkopf suggested the metabasalts were erupted along normal faults related to crustal extension. Lithogeochemical studies currently underway on the Mudjatik mafic granulites and amphibolites should help clarify the presumed continental setting of the Mudjatik Domain.

Iron-rich rocks in the Mudjatik Domain occur in both volcanic and sedimentary environments. It is possible and most likely that iron formation was deposited during a number of episodes, as shown by the numerous thin horizons in the mafic granulites and amphibolites, but it is equally plausible that the major iron formation units are diachronous, being deposited contemporaneously with both volcanics and sediments. The author considers the iron formations to have formed by exhalative processes related to volcanism in the Mudjatik Domain.

Favourable host rocks for gold mineralization in the Mudjatik Domain include the widespread oxide-facies banded iron formation, mafic granulites and ultramafic intrusions. A similar host rock association for gold mineralization is found in the Archean Murchison and Southern Cross Provinces of the Yilgarn Block in the Western Australian Shield (Groves and Phillips, 1988). According to them, this type of stratigraphic association, comprising mainly basaltic volcanics, stable platform sediments and oxide-facies banded iron formation, is consistent with the tectonic setting for platform-phase greenstones. Extensional tectonics are minimal in this setting. The Mudjatik Domain appears to represent a transition between purely platform-phase greenstones and rift-phase greenstones, in that localized rifting of the Mudjatik platform helped control sites of deposition, volcanism and intrusion.

Geochronological studies in the Mudjatik Domain are still at an early stage. The results to date indicate the presence of extensive Archean crust that underwent a major regional thermotectonic event about 2000 Ma (Bickford et al., 1986, 1987) and was strongly affected by the Hudsonian Orogeny about 1850 Ma ago. A variety of granulite facies rocks contain clear euhedral zircons, which yield the 2000 Ma age, and thus may indicate the timing of the granulite facies metamorphism. The Junction Granite (Sibbald, 1974), a late megacrystic granite, yields a Hudsonian age of 1820 Ma (Bickford et al., 1986), but also contains relict xenocrystic zircons which are believed to have been incorporated during anatexis of the Archean crust. The megacrystic and porphyritic granites at Ithingo Lake and the massive to weakly foliated granites at Porter Lake may also be of Hudsonian age. A more thorough discussion of the geological history awaits the results of geochronological studies to be carried out following this field season.

7. References

Alcock, F.J. (1935): Mudjatik-Haultain area, Saskatchewan; Geol. Surv. Can., Mem. 180, 16p.

Bickford, M.E., Van Schmus, W.R., Macdonald, R., Lewry, J.F. and Pearson, J.G. (1986): U-Pb zircon geochronology project for the Trans-Hudson Orogen: current sampling and recent results; *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep. 86-4, p101-107.

Bickford, M.E., Van Schmus, W.R., Collerson, K.D. and Macdonald, R. (1987): U-Pb zircon geochronology project: new results and interpretations; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p76-79.

Breitkopf, J.H. (1988): Iron formations related to mafic volcanism and ensialic rifting in the Southern Margin Zone of the Damara Orogen, Namibia; Precam. Research, v38, p111-130.

Groves, D.I. and Phillips, G.N. (1988): The genesis and tectonic control on Archaean gold deposits of the Western Australian Shield - a metamorphic replacement model; Ore Geol. Rev., v2, p287-322.

Harper, C.T.(1983): Iron ores of northern Saskatchewan; Sask. Energy Mines, Rep. 220, 102p.

Lewry, J.F. and Sibbald, T.I.I. (1977): Variation in lithology and tectonometamorphic relationships in the Precambrian basement of northern Saskatchewan; Can. J. Earth Sci., v14, p1453-1467.

Mawdsley, J.B. (1960): Iron ore occurrences northwestern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 50, 19p.

Pearson, D.E. (1977): The geology of the Mudjatik area (southwest quarter), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 166, 31p.

Pearson, D.E. and Lewry, J.F. (1974): Large-scale fold interference structures in the Mudjatik River area of northern Saskatchewan; Can. J. Earth Sci., v11, p619-634.

Sibbald, T.I.I. (1974): La Loche (north) area; *in* Summary Report of Field Investigations by the Saskatchewan Geological Survey 1974; Sask. Dep. Miner. Resour., p38-45.

_________ (1975): Investigation of certain radiometric anomalies in Crown Reserve 621; *in* Summary of Investigations 1975 by the Saskatchewan Geological Survey; Sask. Dep. Miner. Resour., p123-129.

Sibbald, T.I.I., Munday, R.J.C. and Lewry, J.F. (1977): The geological setting of uranium mineralization in northern Saskatchewan; *in* Dunn, C.E. (ed.), Uranium in Saskatchewan; Sask. Geol. Soc., Spec. Publ. 3, p51-99.

Project 8807

The Wollaston Group and its Underlying Archean Basement in Saskatchewan: Preliminary Report[1]

I.R. Annesley[2] *and C. Madore*[3]

Annesley, I.R. and Madore, C. (1988): The Wollaston Group and its underlying Archean basement in Saskatchewan: preliminary report; *in* Summary of Investigations 1988; Saskatchewan Geological Survey; Saskatchewan Energy Mines, Miscellaneous Report 88-4.

This paper outlines the beginning of an intended three-year study directed towards investigating, in detail, the geological characteristics of the Wollaston Group and the underlying Archean basement (i.e., mainly the Wollaston Domain) with respect to uranium mineralization. To date, the Wollaston Domain in Saskatchewan has been mapped essentially at a reconnaissance level (Lewry and Sibbald, 1979), although detailed mapping, where outcrop permits, has been done in the vicinity of the uranium mines (e.g., Sibbald, 1978). Recently, the Wollaston Domain geology has been compiled at a 1:250,000 scale (Compilation Bedrock Geology Map Series, Saskatchewan Energy and Mines). However, at this scale, the stratigraphy of the Wollaston Group and its underlying Archean basement have not been defined well enough to permit discrimination between favourable and unfavourable mineralized areas.

1. Objectives

The objectives of this study are:

1) to provide a **new compilation** of existing stratigraphic, structural and lithogeochemical data of the Wollaston Group, supplemented with new field data collected over the next 2 1/2 years, so as to establish more definitively the stratigraphy of the Wollaston Group;
2) to introduce a more **formal classification** of the metasedimentary rock units of the Wollaston Group;
3) to examine **selected areas** in detail to establish and permit correlation of stratigraphic profiles, especially near principal sites of uranium mineralization;
4) to determine the **lithologic controls,** if any, of the Archean/Aphebian rocks on the genesis of unconformity-type uranium deposits; and
5) to determine, likewise, the **role of Hudsonian metamorphism** (including retrogression) and deformation in the genesis of unconformity-type uranium deposits.

This information can then be applied to the metallogenesis of uranium deposits and mineral exploration in the region. A short field season in 1988 was carried out by a two-person field party in three areas (Figure 1): 1)Beaudreau Lake, 2) Key Lake Road (km 70 to km 220), and 3) Key Lake Mine.

This field work served as an introduction to the stratigraphy of the Wollaston Group, and to the structural-metamorphic complexities of the Wollaston Group and its underlying Archean basement. Other progress to date includes sample preparation for petrography and geochemistry, and establishment of a formal classification of the Wollaston Group metasediments.

2. Classification: Wollaston Group Metasediments

A review of the geological literature, together with field observations of the rocks, reveals a lack of consistency in Wollaston Group metasediment nomenclature. Gilboy (1982) recognized this problem and re-examined in detail the classification for clastic metasediments. The present authors agree with the mineralogical and geochemical characteristics of his classification, but do not accept the naming of the rocks as pelites, semipelites, and psammites, even if the modifier 'meta-' is assumed. We argue that the Wollaston Group metasediments are high-grade metamorphic rocks and their rock names should reflect this. We propose, instead, the following (tentative) modified version of Gilboy's (1982, 1985) classification:

Gilboy (1985)	*Annesley & Madore (this paper)*
Quartzite	Metaquartzite
Arkosic Psammite	Psammitic gneiss/schist
Semipelite	Psammopelitic gneiss/schist
Pelite	Pelitic gneiss/schist

Note that further subdivisions of this classification can be made by adding 'mineral name' modifiers to the rock name (e.g., pelitic garnet-biotite gneiss).

The authors feel that this classification is more useful because it provides the metamorphic rock name (textural basis) plus the genetic interpretation and mineralogical composition of the rock. Also, the genetic modifier can be dropped if one is not certain of the origin of the rock,

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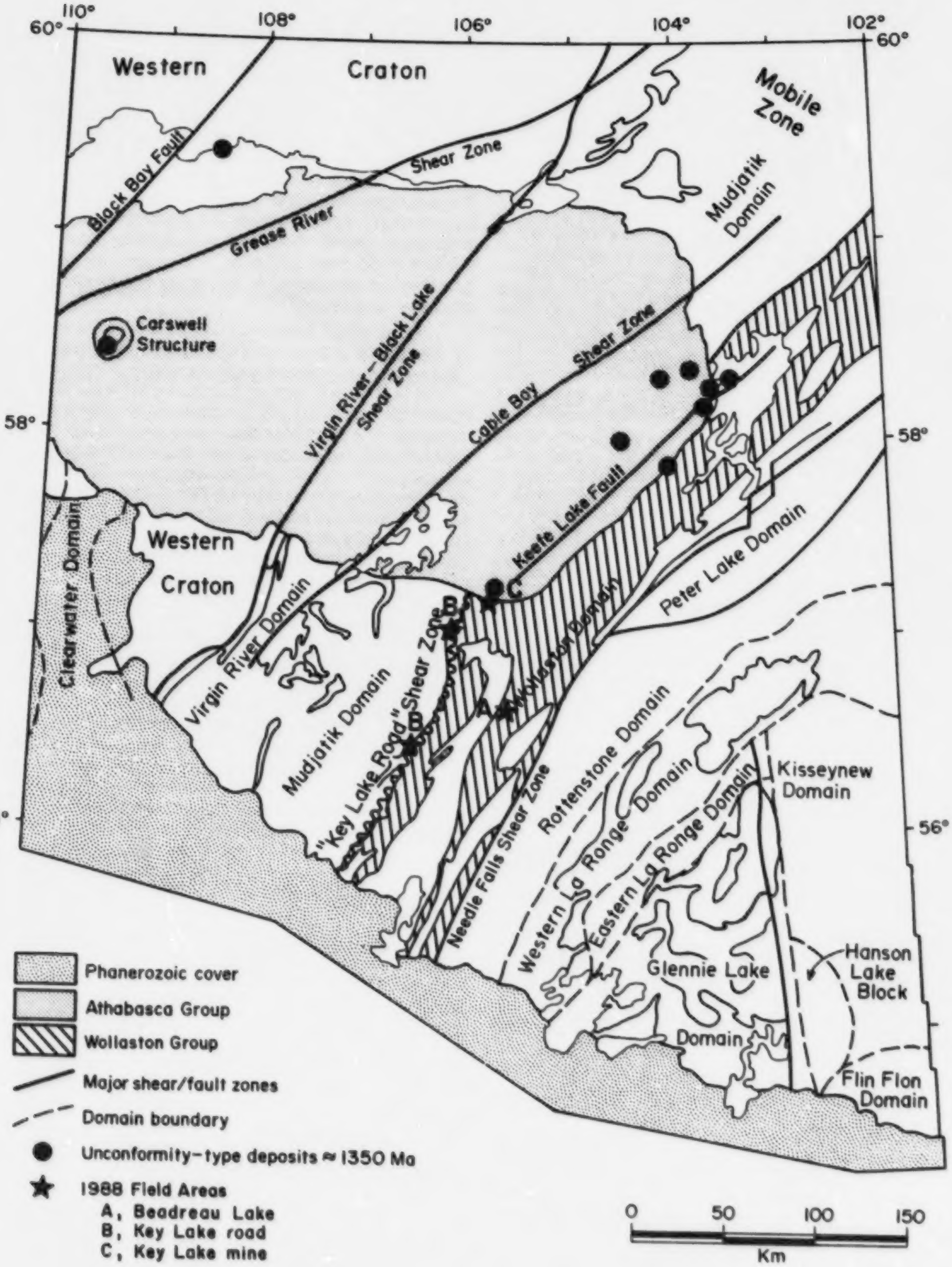
110°
108°
106°
104°
102°
60°
60°
58°
58°
56°
56°
Western Craton
Mobile Zone
Black Bay Fault
Shear Zone
Grease River
Mudjatik Domain
Carswell Structure
Virgin River–Black Lake Shear Zone
Cable Bay Shear Zone
Keefe Lake Fault
Clearwater Domain
Western Craton
Virgin River Domain
Virgin River Domain
Mudjatik Domain
"Key Lake Road" Shear Zone
Wollaston Domain
Peter Lake Domain
Needle Falls Shear Zone
Rottenstone Domain
Western La Ronge Domain
Eastern La Ronge Domain
Kisseynew Domain
Hanson Lake Block
Glennie Lake Domain
Flin Flon Domain
A
B
B
C
Phanerozoic cover
Athabasca Group
Wollaston Group
Major shear/fault zones
Domain boundary
Unconformity-type deposits ≈ 1350 Ma
1988 Field Areas
A, Beadreau Lake
B, Key Lake road
C, Key Lake mine
0
50
100
150
Km

Figure 1 - Location map with geological boundaries.

a situation common in the field. The genetic modifier can be added later after petrographic and geochemical data become available.

3. Beaudreau Lake Area

Two weeks of detailed mapping were spent looking at some of the major lithological units of the type area for Money's (1966) 'Daly Lake Group'. More recently, Ray (1981) incorporated these metasediments within the more extensive Wollaston Group and suggested that the term Daly Lake Group be dropped. Five distinct lithological units of Money's 'Daly Lake Group' were examined. Exposures are generally poor with heavy lichen cover, except those along some lake shorelines. Primary textures and structures are rare and only a few gradational contacts were observed; hence, the relative ages of the different units are uncertain. Also, the area is structurally complex, thus making stratigraphic interpretation difficult.

a) Pelitic Gneisses (Biotite-Cordierite Rocks, etc. – Money, 1966)

These rocks form a major part of the stratigraphy within the map area (Money, 1966). They commonly occur interlayered with or gradational into psammopelitic and psammitic gneisses and generally comprise magnetite-cordierite-biotite-quartz-feldspar with minor garnet and/or sillimanite. Different shades of grey are characteristic of fresh surfaces and dull grey to rust colours of weathered surfaces. The rocks vary from fine to medium grained and essentially equigranular to fine to coarse grained and inequigranular-porphyroblastic. Gneissic layering ranges from well to poorly developed on a scale ranging from centimetres to metres.

Migmatization has occurred, yielding up to 40 percent leucosomes as layers, lenses and pods. These granitic segregations are of at least two generations. The early (one or more ?) generations are fine grained and occur as *lit-par-lit* veinlets parallel to the early fabrics of the rocks. The younger segregations are coarse grained (i.e., pegmatitic) and occur as pink pods and lenses which locally crosscut the early segregations. The younger segregations may be related to the late shearing fabric which overprints all earlier fabrics. Possibly coeval with the two or more generations of granitic segregations are two habits of porphyroblastic cordierite (and possibly K-feldspar). Cordierite occurs as greenish to bluish-grey poikiloblasts up to 1.0 cm in size, and purplish-blue anhedral porphyroblasts or aggregates in the late pegmatitic segregations. Red porphyroblastic garnets are also present, constituting from trace amounts to up to 5 percent of the rock. Up to 7 percent magnetite is also typical.

b) Psammopelitic Gneisses (Biotite Gneisses and Granulites – Money, 1966)

The psammopelitic gneisses also form a significant portion of the stratigraphic succession in the map area (Money, 1966). At Beaudreau Lake, they are gradational into and sometimes interlayered with the pelitic, psammitic and calc-silicate gneisses. At one locality, they are calcareous and appear to mark a gradational boundary between pelitic gneisses and calc-silicate gneisses. The gneisses are dull dark brown to grey on weathered surfaces and medium grey with pink interlayers on fresh surfaces. The most common variant of these gneisses is fine grained, essentially equigranular and poorly to well layered, with 5 to 30 percent *lit-par-lit* layers (millimetre scale), lenses and pods of granitic composition. As above, these granitic segregations are of at least two different generations; however, there appears to be an overall decrease in their abundance when compared to the pelitic gneisses. This may be a function of lithologic type or stratigraphic position. Small porphyroblasts of amphibole, garnet, K-feldspar or magnetite up to 7.5 mm in diameter also occur. The psammopelitic gneisses are interpreted as metamorphosed siliceous shales or greywackes.

c) Psammitic Gneisses (Meta-arkose and Quartzofeldspathic Rocks – Money, 1966)

Psammitic gneisses form the other major unit of the stratigraphy in the Daly Lake 'type locality' area. However, Beaudreau Lake is northwest of the major outcropping of this unit. In the few exposures observed, these rocks are off-white to pinkish-grey on weathered and flesh-pink, spotted with dark green on fresh surfaces. Typically, they are fine to medium grained, homogeneous to heterogeneous, massive to well layered and colour-banded. The colour-banding varies from millimetre to metre scale where present, and in some cases is clearly related to compositional variations. Locally, it is associated with what is thought to be graded bedding marked by variations in grain size from very fine (formerly siltstones and shales) to medium (formerly sandstones). The rocks are essentially quartzofeldspathic, but contain minor biotite, amphibole, garnet and tourmaline. No sharp contacts associated with this unit were observed, and therefore its stratigraphic relationship at Beaudreau Lake is uncertain. The psammitic gneisses are interpreted as metamorphosed sandstones of various types.

d) Calc-Silicate Gneisses (Calc-Silicate Rocks – Money, 1966)

These gneisses make up only a small part of the stratigraphic succession of the region (Money, 1966). The major locality of calc-silicate gneisses outcrops just west of Beaudreau Lake. They are highly variable in texture and composition, fine to coarse grained, massive to well layered, essentially equigranular to inequigranular-porphyroblastic and uniformly coloured to colour-banded. Compositionally, they consist of variable amounts of diopside, amphibole, biotite, K-feldspar, quartz, plagioclase, scapolite, magnetite, sphene, calcite, epidote and forsterite(?). Locally, abundant granitic segregations with up to 1 cm diameter magnetite crystals are present. In places, the rocks are highly porphyroblastic with abundant diopside crystals up to 5 cm in size. In areas of strong deformation, a pronounced augenitic fabric with large eyes of diopside, amphibole and granitic material is developed. The calc-silicate gneisses are interpreted to be metamorphosed argillaceous limestones and calcareous shales.

e) Metadiorite (Hornblende-Biotite Rocks and Amphibolite – Money, 1966)

This rock unit forms a very small part of the stratigraphy of the area and only one outcrop was examined near Beaudreau Lake. At this locality, it is fine to medium grained, essentially equigranular and massive to weakly gneissose with a granoblastic to weak nematoblastic texture. Compositionally, the rock consists of plagioclase, hornblende, biotite and minor quartz. It is interpreted as a small pluton or sill/dyke.

f) Structure and Metamorphism

The rocks of the Beaudreau Lake area exhibit polyphase folding and metamorphism. Initial observations, especially in the pelitic gneisses, indicate evidence of at least four major deformational events. The earliest (D_1) is considered to have produced the general gneissosity, although no fold structures associated with this gneissosity development were recognized. Superimposed D_2 folds trend north-northeast (015° to 040°) and D_3 folds east-northeast (050° to 075°), both with moderate plunges. The superposition of the D_2 and D_3 fold sets is clearly observed on some outcrop surfaces by the presence of fold interference patterns. Initial observations indicate a mixed fold pattern intermediate between Ramsay's types 0 and 3 (Ramsay and Huber, 1987). Weakly to strongly developed colinear mineral stretching and intersection lineations are common and probably contemporaneous with the fold sets, and well-developed rod and mullion fabrics are observed locally. The latest deformation (D_4) is interpreted as a shearing event responsible for rotating and transposing all earlier fabrics and structures. It is especially evident in the pelitic gneisses by the presence of a moderately to strongly developed C-S fabric (Berthé et al., 1979). The C-S fabric is accompanied by rotated feldspars and asymmetric pull-aparts. These fabric structures indicate, in most cases, an apparent dextral sense of shear.

Initial field observations of the mineral assemblages present in the Beaudreau Lake area indicate low-pressure middle to upper amphibolite grade of metamorphism. However, a more careful examination of outcrops and hand specimens revealed some partially greasy-waxy patches, which may indicate either retrogression from granulite grade or peak metamorphism near granulite grade conditions.

4. Key Lake Road

One week of detailed mapping and sampling was carried out along the Key Lake road between kilometres 70 and 220. The best exposures were those which had been blasted during road construction and those burnt over within the past ten years. These outcrops clearly reveal the structural/metamorphic complexity of the Wollaston and Mudjatik Domains, and of their boundary. More field mapping is required in this area in order to unravel the stratigraphy of the lower part of the Wollaston Group. This will entail looking through the complex structural/metamorphic overprint to define the characteristics and 'true' thicknesses of the Wollaston Group metasediments. The geology along the Key Lake road has been mapped largely on a 1:100,000 or a 1:250,000 scale (Munday, 1977; Gilboy, 1985; Ray, 1983). The authors identified five distinct lithological rock types and one of unknown genesis.

a) Pelitic and Psammopelitic Gneisses (Wollaston Group)

These gneisses form the major part of the Wollaston Group in this area. They are similar in composition and mineralogy to those found in the Beaudreau Lake area, but are more intensely deformed, thus causing difficulties in subdividing pelitic and psammopelitic gneisses in the field. The rocks are light to medium grey with pink interlayers on the fresh surfaces, and weather dull grey to rusty brown. They are quite heterogeneous, typically fine to coarse grained, equigranular to inequigranular-porphyroblastic, well banded, highly deformed, tightly folded and locally well sheared (i.e. mylonitic). A moderate to strong C-S fabric is characteristic, as are Z-shape, S-shape, sheath and intrafolial folds. Porphyroblasts of K-feldspar and cordierite up to 10 cm in size (average 1 to 2 cm) are generally present, especially within granitic segregations. As at Beaudreau Lake, two generations of cordierite were recognized. Other porphyroblasts or megacrysts of minor occurrence include garnet, magnetite and/or tourmaline.

Invariably, the pelitic to psammopelitic gneisses contain *lit-par-lit* and crosscutting layers, lenses, veinlets and pods of granitic composition, and of at least three generations. They provide useful markers for elucidating the deformational history of the rocks. These continuous to discontinuous segregations represent deformed granitic dykes and *in situ* (or injected) anatectic melts (i.e., migmatitic), indicated respectively by crosscutting or conformable relationships. The granitic dykes commonly exhibit ptygmatic folding, boudinage, attenuation and asymmetric pull-apart structures.

b) Calc-Silicate Gneisses and Marble (Wollaston Group)

Calc-silicate gneisses and marble form a very minor component of the stratigraphic succession along the Key Lake road. Their contact relationships with the other lithological units are not known because only two isolated outcrops were observed. The rocks are compositionally banded with alternating layers of fine-grained, light grey marble and coarse-grained, dark grey to green calc-silicate gneiss. They have also undergone a high degree of deformation, as shown by tightly folded, boudinaged and attenuated layers. A well-developed C-S fabric is present. Both Z- and S-shape folds are common.

c) Psammitic Gneisses (Wollaston Group)

The psammitic gneisses form the other major unit of the Wollaston Group in this area. The intense deformation of the rocks along the boundary of the Wollaston and Mudjatik Domains does, however, cause difficulties in distinguishing these gneisses from highly sheared granitoids. Where outcrop permitted observation of the transition from relatively low-strain into high-strain zones, subtle differences could be discerned and definitive identification was possible. In instances where this was not the case, the rocks were classified as highly sheared quartzofeldspathic gneisses (mylonites) of uncertain genesis. The recognizable psammitic gneisses are light to medium shades of grey, pink and green on the fresh and weathered surfaces. They are typically fine to medium grained, granoblastic to cataclastic, recrystallized, moderately to well foliated and low in mafics, which are concentrated in thin laminae and consist of amphibole, chlorite, biotite and epidote. Locally, the laminae are centimetre scale and coarse grained. These rocks contain from 10 to 15 percent granitic segregations and veins.

d) Foliated to Gneissic Granitoids (Assumed to be Archean)

These rocks, which constitute the major part of the Mudjatik Domain, are excellently exposed along the Key Lake road, especially between kilometres 100 and 140 where the outcrop has been recently burnt over. They comprise a variable suite of off-white and pinkish red, fine-grained to coarse-grained, essentially equigranular to inequigranular-porphyritic (megacrystic where not certain of genesis), weakly foliated to gneissic granites and granodiorites. Biotite and/or hornblende, quartz and feldspar with minor accessories are typical constituents. Numerous pegmatitic and aplitic sills and dykes of granitic composition exhibit crosscutting relationships. Approaching the Mudjatik/Wollaston boundary, the granitoids become highly sheared and exhibit distinct mylonitic C-S fabrics and agmatitic textures.

e) Biotite-Bearing Quartzofeldspathic Gneisses (Assumed to be Archean)

These gneisses form a minor component of the Mudjatik Domain, occurring as infolded interlayers within the gneissic granitoids. Typically, they are colour and compositionally banded (centimetre scale), fine to medium grained, essentially equigranular, granoblastic to gneissose and tightly folded. Their gneissosity is defined by alternating granoblastic quartzofeldspathic and schistose biotite-bearing layers.

f) Quartzofeldspathic Gneisses of Uncertain Genesis (Mylonites)

Most of these gneisses are very fine to medium grained, 'cherty' to 'flinty-crushed' and moderately to strongly banded with a gneissic or cataclastic/mylonitic foliation. They vary from relatively homogeneous to extremely heterogeneous. Some contain abundant lenticular to augenitic heterogeneities, locally with large porphyroclasts, and are interpreted as former granitic pegmatites and aplites. In general, these rocks are thought to represent highly sheared gneissic granitoids, although they could also be highly sheared psammitic gneisses.

g) Structure and Metamorphism

The area has been highly deformed, with most rocks possessing a well-developed to intense, invariably mylonitic/cataclastic foliation. Most of the rocks have a pervasive C-S fabric, indicative of high strain (ductile with ductile-brittle subdomains). Other indicators of this high-strain zone include 1) rotated porphyroblasts or porphyroclasts, 2) δ -structure, 3) σ -structure, 4) dynamic recrystallization, 5) *en-echelon* vein arrays, 6) ptygmatic folding, 7) sheared-off fold limbs, and 8) sheath folds (Ramsay and Huber, 1987). Based on the abundance of small-scale shear structures, the authors interpret the boundary of the Mudjatik and Wollaston Domains as a ductile shear zone with some ductile-brittle subdomains, and propose the informal name 'Key Lake Road Shear Zone' for this structure. Further field work, next summer, will try to define its characteristics and boundaries, and determine if the zone is typical of the Archean/Aphebian boundary in general. Its role with respect to the formation of unconformity-type uranium deposits will also be examined.

Five deformational events (D_1 to D_5) were recognized in this area. The D_1 to D_3 events are considered to be equivalent to those at Beaudreau Lake. All primary features of the Wollaston Group metasediments have been obliterated. Rare intrafolial folds are present and are considered to have formed during D_1. These folds and the regional gneissosity were then refolded by two sets of upright folds during D_2 and D_3. The geometric relationships of these fold sets are deduced by the complex interference patterns observed on outcrop surfaces. The geometry appears to be variable, as both type 1 (e.g., sheath folds) and type 3 fold forms were found. Locally, a phase (D_4 – timing ?) of late open upright folding has produced broad warps in the earlier fabrics. The latest deformational event (D_5), marked by strong shearing, has rotated and transposed the earlier fabrics into a dominant north-northeast foliation.

Mineral assemblages present in the Wollaston Group rocks, away from the Mudjatik – Wollaston boundary, are indicative of middle to upper amphibolite-grade metamorphism. However, in the high-strain zone, these rocks show evidence of retrogression, as illustrated by the presence of epidote, chlorite and sericite. The metamorphic grade of the Archean rocks most likely reached granulite conditions because the biotite-bearing quartzofeldspathic gneisses commonly exhibit a greasy waxy lustre. However, no granulite-grade mineral assemblages were identified in the field, and petrographic work will be required to define metamorphic grade of these rocks more precisely.

5. Key Lake Mine Area

The authors spent three days at the Key Lake Mine site and immediate area to become familiar with the geology of the Key Lake uranium deposits. The geological characteristics of these deposits are excellently summarized by Dahlkamp (1978) and de Carle (1986), among others. Mineralization is present within open fractures and as replacement ore, locally within sheared mylonites, at the intersection of a northeasterly-trending reverse fault and the sub-Athabasca Group unconformity. The history of the mineralization is extremely complicated, as is the geology. The mineralization is, apparently, mainly structurally controlled.

Initial work at the mine site concentrated on observing and collecting relatively fresh drill core samples of the Wollaston Group and underlying Archean basement rocks. Particular attention was given to the quartzofeldspathic gneisses at the Archean/Aphebian boundary, which have been mapped or core-logged, both as sheared Archean granitoids or Aphebian meta-arkoses, the latter classification being generally preferred. However, because of mineralogical and textural similarities between core samples and those field samples positively identified as granitoid, the present authors interpret the core sample gneisses as highly sheared (mylonitic) Archean granitoids. Further work is warranted to satisfactorily resolve this identification problem. Several other preliminary observations are possible from the examination of the drill core:

1) High graphite content is characteristic of high-strain zones; it probably was concentrated in these zones as they developed.
2) Pervasive C-S fabrics in the Archean/Aphebian boundary rocks are similar to those of the Mudjatik/Wollaston boundary.
3) The highly deformed nature of the Wollaston Group metasediments may well imply much stratigraphic repetition by folding and thrusting.

One additional comment can be made regarding an outcrop, southwest of Key Lake, previously mapped as meta-arkose. It consists of a relatively homogeneous, moderately to well-foliated granitoid, assumed to be Archean in age. The granitoid has been intruded by several phases of pegmatite and aplite, has a moderately developed C-S fabric, and includes xenolithic blocks of uncertain origin. This rock is very similar to the granitoids observed along the Key Lake road and at the mine site, the only differences being attributed to different deformation states and/or different plutonic bodies. In light of these observations, a careful re-examination of the quartzofeldspathic gneisses at the Archean/Aphebian boundary and within the Wollaston Domain would seem to be essential.

6. Future Work and Release of Results

Immediate work will concentrate on:

1) a petrographic and geochemical study of samples collected from this summer's field work;
2) compilation and correlation of existing stratigraphic and lithogeochemical data of the Wollaston Group;
3) a petrographic and geochemical study of company samples, kindly loaned by G. Ruhrmann (Key Lake Mining Corporation); and
4) discussions with other members of the mining industry.

Potential field areas selected for next summer are:

1) Key Lake road, including Karpinka Lake,
2) Rabbit Lake and surrounding area,
3) Upper Foster Lake and Karin Lake,
4) Highrock Lake, and
5) Daly Lake.

Publication of compiled results of this year's work will be released as a Saskatchewan Research Council (SRC) report by the senior author. Detailed and regional scale results of future field work will be published in the Saskatchewan Geological Survey annual Summary of Investigations. Any confidential material will be filed in Saskatchewan Research Council confidential reports.

7. Acknowledgements

To begin working on a project of this scope, it is important to discuss and exchange ideas with some of the more experienced researchers of the study area. The authors have had that opportunity and would like to thank several people for introducing us to the problems of Wollaston Group stratigraphy with respect to uranium mineralization. These people include: G. Ruhrmann of Key Lake Mining Corporation (KLMC); K. Kogler, B. Tan and K. Lehnert-Thiel of Uranerz Exploration and Mining Ltd.; T.I.I. Sibbald, R. Macdonald, D.J. Thomas and A.J. Gracie (La Ronge Resident Geologist) of Saskatchewan Energy and Mines (SEM); and M. Mellinger and D. Quirt of the Saskatchewan Research Council (SRC).

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8. References

Berthé, D., Choukroune, P. and Jegouzo, P. (1979): Orthogneiss, mylonite and non-coaxial deformation of granites: the example of the South American Shear Zone; J. Struct. Geol., v1, p31-42.

Dahlkamp, F.J. (1978): Geological appraisal of the Key Lake U-Ni deposits, northern Saskatchewan; Econ. Geol., v73, p1430-1449.

de Carle, A.L. (1986): Geology of the Key Lake deposits; *in* Evans, E.L. (ed.), Uranium Deposits of Canada; Can. Inst. Min. Metall., Spec. Vol. 33, p170-177.

Gilboy, C.F. (1982): Classification of clastic metasediments; Sask. Energy Mines, Open File Rep. 82-3, 33p.

________ (1985): Basement geology, part of the Cree Lake (south) area; Sask. Energy Mines, Rep. 203, 47p.

Lewry, J.F. and Sibbald, T.I.I. (1979): A review of the pre-Athabasca basement geology in northern Saskatchewan; *in* Parslow, G.R. (ed.), Uranium Exploration Techniques; Sask. Geol. Soc., Spec. Publ. 4, p19-58.

Money, P.L. (1966): The geology of the Daly Lake area (east half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 108, 48p.

Munday, R.J.C. (1977): The geology of the Mudjatik (east) area, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 168, 25p.

Ramsay, J.G. and Huber, M.I. (1987): The Techniques of Modern Structural Geology, Volume 2: Folds and Fractures; Academic Press Inc., Orlando, p309-700.

Ray, G.E. (1981): Bedrock geology and geochemistry, Daly Lake (west) area and part of Middle Foster Lake area; Sask. Miner. Resour., Rep. 208, 33p.

________ (1983): Compilation bedrock geology, Geikie River, NTS area 74H; Sask. Energy Mines, Rep. 229 (1:250,000 scale map with marginal notes).

Sibbald, T.I.I. (1978): Uranium metallogenic studies: Rabbit Lake, geology; *in* Summary of Investigations 1978, Sask. Geol. Surv., Misc. Rep. 78-10, p56-60.

Project 8833

Bedrock Geological Mapping, Patterson Island Area, Reindeer Lake (part of NTS 64E-10)[1]

D.G. MacDougall

MacDougall, D.G. (1988): Bedrock geological mapping, Patterson Island area, Reindeer Lake (part of NTS 64E-10); *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

This project was completed to determine whether 1) the Patterson Island pluton (Stauffer et al., 1981; Macdonald and Thomas, 1983), a subcircular body of megacrystic diorite, is a late-stage posttectonic intrusion or part of the Swan River gabbroic rocks (op. cit.), 2) the Swan River gabbroic rocks show primary cumulate layering, and 3) nearby iron formation and other metasedimentary rocks are correlative with the Campbell River Group.

The area encompasses a group of islands closing off the entrance to a large indented bay on the northwest side of Reindeer Lake. Excellent exposures present along the lakeshore are a result of recent low lake levels.

1. Regional Geology and Previous Work

Regional mapping by Stauffer et al. (1981) outlined a roughly circular body of megacrystic diorite on Patterson Island, set in the Swan River gabbroic rocks, a heterogeneous assemblage of gabbros, diorites and monzonites. Regional mapping by Lewry et al. (1980, 1981) determined that about one-third of the Peter Lake Domain consists of similar gabbroic-dioritic rocks, some of them layered (Potter 1979), intruded by and enclosed within granitic rocks. Similar gabbroic rocks to the southwest in the Parker Lake Shear Zone have been dated at 2538 ± 10 Ma by the U-Pb zircon method (Ray and Wanless 1980)

Husky Oil Ltd. (1970) drilled and trenched a ground EM anomaly and outlined minor sulphide mineralization near a graphitic shear zone northwest of Wiley Bay (Wiley Bay showing, Saskatchewan Mineral Deposits Index No. 569). Lacana Exploration Inc. (1986) recently investigated the Wiley Bay showing and parts of the Swan River gabbroic suite for platinum group metal (PGM) potential.

This study shows that the megacrystic diorite[2] of the Patterson Island pluton is, in fact, a component layer within a gabbroic-dioritic complex, termed here the Patterson Island gabbroic suite, which is separated from the Swan River gabbroic rocks by an enclave of supracrustals (Figure 1).

2. Patterson Island Gabbroic Suite

Table 1 shows the range of modal compositions as determined from thin sections.

Megacrystic diorite (unit Dmc) underlies most of the southern part of Patterson Island and outcrops as a narrow band on the west shore of Patterson Channel. The rock is pinkish grey to dark grey, coarse to very coarse grained, and comprises grey, violet-grey to pink potassic feldspar megacrysts (from 10 to 75 percent; average 45 percent; 1 to 4 cm in length) set in a fine-grained groundmass of cream-coloured plagioclase, black hornblende/augite, biotite and minor magnetite.

Syenomonzonite (unit Mzs) outcrops as a circular strip underlying Patterson Channel and curving northeast and east across the middle of Patterson Island and southwards along its eastern shore. The rock is pink, predominantly coarse to locally medium grained, and contains, in places, up to 5 percent of 1 to 2 cm potassic feldspars set in an equigranular groundmass of pink potassic feldspar, cream to grey-green plagioclase, black hornblende, biotite, minor magnetite and very fine-grained quartz.

Monzonite (unit Mzd) is present towards the western side of the map area. It is a pinkish grey, white-weathering medium-grained, equigranular rock characterized by the presence of equal proportions of pink potassic feldspar and white plagioclase, the predominance of biotite over hornblende, a sparsity of magnetite and a low colour index (10 to 30). In outcrop it is distinguished only with difficulty from leucogabbro (unit Gbl).

Leucogabbro (unit Gbl) is interbanded with melagabbro (unit Gbm) on a large and small scale and is most common west of Patterson Channel. The rock is light to medium grey (colour index 37 to 51), coarse to rarely medium grained, and locally contains sparse scattered 2 to 4 cm potassic feldspar megacrysts set in an equigranular groundmass of grey plagioclase, black hornblende/augite, biotite and minor magnetite.

Melagabbro (unit Gbm) outcrops in a series of roughly concentric southwest- to southeast-trending strips on the mainland west of Patterson Channel and on the east and west sides of Patterson Island. It is a grey to dark grey (colour index 42 to 58), coarse-grained rock com-

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(1) Project funded under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89

(2) The prefix 'meta-' has been omitted from all but a few rock names, as they have all suffered some degree of regional metamorphism

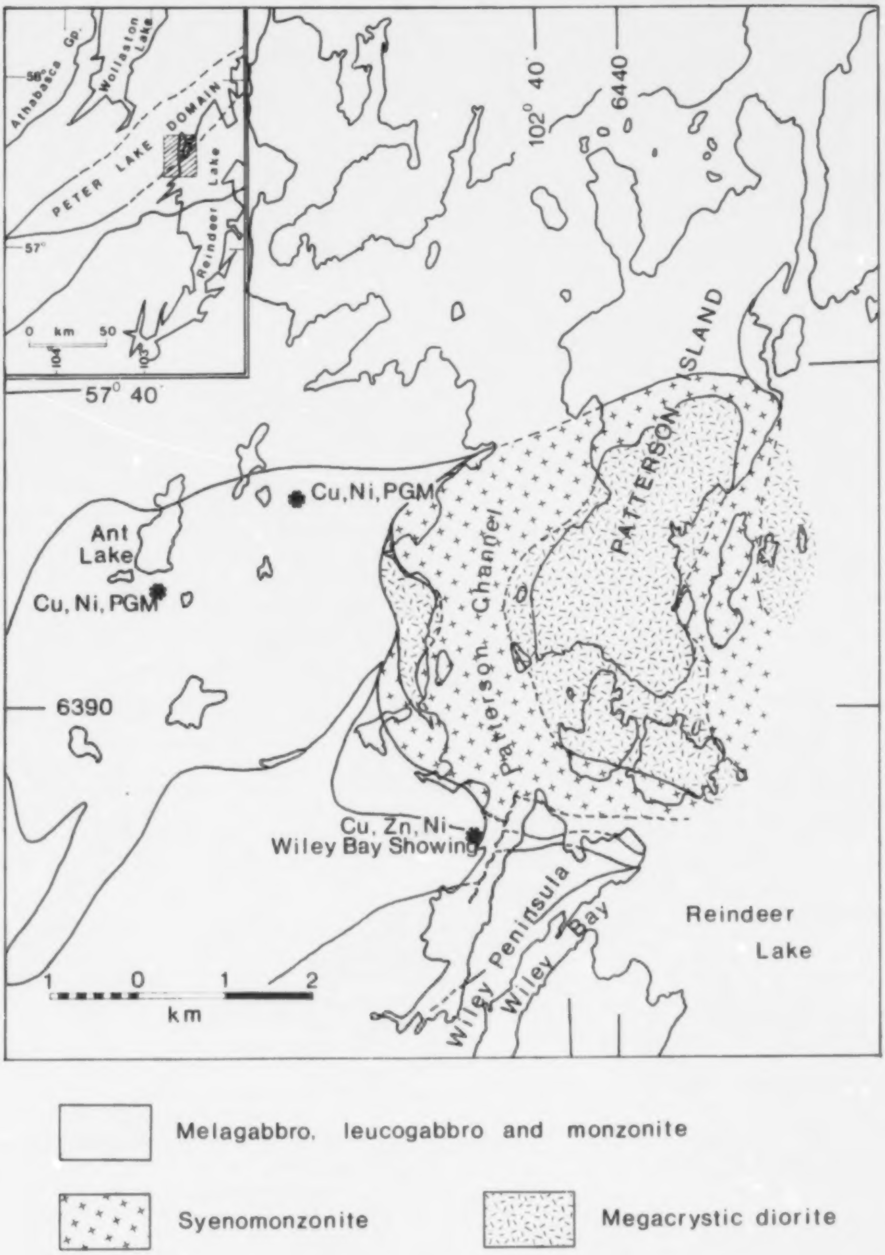
58°
Athabasca Gp.
Wollaston Lake
PETER LAKE DOMAIN
Reindeer Lake
57°
0 km 50
104°
103°
102° 40'
6440
57° 40'
PATTERSON ISLAND
Patterson Channel
Cu,Ni,PGM
Ant Lake
Cu, Ni, PGM
6390
Cu, Zn, Ni
Wiley Bay Showing
Wiley Peninsula
Wiley Bay
Reindeer Lake
1 0 1 2
km
Melagabbro, leucogabbro and monzonite
Syenomonzonite
Megacrystic diorite

Figure 1 - General geology of the Patterson Island area.

posed of an equigranular mixture of white plagioclase, black hornblende/augite, biotite and minor magnetite.

Metapyroxenite (unit Mpx) occurs in narrow but persistent bands or as xenolithic remains within the melagabbro. The rock is dark green, coarse to very coarse grained, and has characteristic knobbly-weathering surfaces. It is composed of minor plagioclase and large crystals of green amphibolitized augite which enclose separate phlogopite plates having identical orientation. Some of the amphibole is present as fans or sheaves of acicular crystals.

Table 1 – Modal Compositions (in Percent) of Patterson Island Gabbroic Suite Rocks

	Rock Unit					
Mineral	*Mzs*	*Mzd*	*Dmc*	*Gbl*	*Gbm*	*Mpx*
K-feldspar	20-70	30	15-50[1]	< 1-50	3-15	-
Plagioclase	20-65	35	40-60	15-48	25-60	0-40
Quartz	< 1-4	-	0-1	0-1	0-1	-
Biotite	< 1-3	20	3-6	1-5	5-10	0-5
Phlogopite	-	-	-	-	-	0-30
Chlorite	-	-	-	-	-	0-1
Hornblende	5-10	5	6-12[2]	7-50[2]	0-14[2]	0-30[2]
Pyroxene	-	-	0-13	0-23	20-45	50-70
Carbonate	-	-	0-< 1	-	-	-
Clinozoisite	-	-	-	0-< 1	-	-
Zoisite	-	-	-	-	0-1	-
Epidote	0-2	2	0-2	0-1	-	-
Apatite	0-< 1	5	0-2	< 1-3	1-3	-
Magnetite	0-< 1	1-2	< 1-3	0-3	3-7	3-10
No. of sections	3	1	3	3	4	4

[1] mostly as megacrysts
[2] partly as rims to pyroxene

a) Foliation and Layering

The megacrystic diorite, syenomonzonite, leucogabbro and melagabbro possess a variably developed planar foliation expressed by alignment of xenoliths, megacrysts and mafic streaks. The foliation is best developed in the diorite and syenomonzonite, and tends to be faint or absent in the gabbros. The syenomonzonite locally displays a well developed gneissosity.

Rhythmic 10 to 30 cm scale cumulate layering is well developed in parts of the gabbros and diorite, but less common and weaker in the syenomonzonite. Well-developed mafic layers have sharp bases. Tops of layering on the southwest side of Patterson Island face east; elsewhere, the mafic layers are not sufficiently well defined to allow top determinations. A parallel large-scale banding reflects variations in concentration of megacrysts in the diorite and melagabbro; 10 to 30 m interbanding of finer and coarser grained leucogabbro and of leucogabbro with megacrystic diorite and melagabbro is also present. The contacts between the interlayered megacrystic diorite, leucogabbro and melagabbro vary from sharp to gradational; contacts between the syenomonzonite and the gabbros are invariably sharp and between the syenomonzonite and the diorite are always gradational.

b) Xenoliths

Supracrustal xenoliths range from rare to abundant in all units of the Patterson Island gabbroic suite, except in the metapyroxenite and monzonite where they are absent. Xenoliths are generally amphibolitic in composition, egg-shaped, 2 to 60 cm long and variably flattened in the foliation plane; in places they form metre-scale swarms locally making up 90 percent of the outcrop. In the gabbros, xenoliths are commonly round to subround or angular and lack a preferred orientation. Rafts of variably migmatized amphibolitic or paragneissic material several tens of metres long are present in the megacrystic diorite, monzonite amd melagabbro along the eastern shore of Patterson Island. Cognate gabbroic xenoliths are locally present in other units and may in some cases represent disrupted cumulate layering. A sequence of cognate xenoliths has been observed: metapyroxenite in both melagabbro and leucogabbro; melagabbro in leucogabbro; and leucogabbro in syenomonzonite.

c) Jointing

Three roughly perpendicular sets of evenly spaced joints 1 to 2 m or 2 to 3 m apart are common in the syenomonzonite, monzonite and megacrystic diorite; closer spacings of 30 to 100 cm are uncommon to rare and confined to narrow zones. Jointing in the gabbros and metapyroxenite is rare.

d) Shearing

Submylonitic to mylonitic shears, 5 to 8 cm wide, are very locally developed in all units of the Patterson Island gabbroic suite except the monzonite.

e) Veining

Sporadic quartz veins are confined to the leucogabbro, syenomonzonite and megacrystic diorite. Potassic feldspar clots and veins, granitic pegmatite patches, quartz-feldspar veins and irregular aplite veins are typically abundant in the melagabbro. Quartz-feldspar, feldspar and aplite veins are present to a lesser extent in the leucogabbro and metapyroxenite. Aplites and pegmatites, which crosscut and in places agmatize the gabbros, are presumed to be derivatives of the syenomonzonite.

f) Alteration

Hematite and epidote are widespread along joints and fractures as well as within shears in megacrystic diorite, syenomonzonite, leucogabbro and melagabbro units. Epidote with variable amounts of hematite forms veins, clots or pods in gabbro and metapyroxenite. Epidotiza-

Table 2 – Radiometric and Magnetic Characteristics of the Patterson Island Gabbroic Suite

	Rock Unit				
	Mpx	*Gbm*	*Gbl*	*Dmc*	*Mzs*
Total Count Radiometrics (cps)[1]	-	< 100-120	110	90-150	100-160
Magnetism[2]	weak	moderately to very strong	weak to moderate	fair to moderate	weak

[1] determined with Scintrex SP-2 scintillometer
[2] determined by reaction to pivoted magnet

tion and hematization are accompanied by saussuritization in mylonitic shear zones that cut melagabbro. Alteration is rare or absent in the monzonite.

g) Mineralization

The syenomonzonite, megacrystic diorite, leucogabbro, melagabbro and metapyroxenite contain trace amounts of disseminated pyrite. Chalcopyrite occurs as disseminations in monzonite, leucogabbro and melagabbro and, with pyrite and malachite, in quartz veins and feldspathic veins cutting leucogabbro. Rare, narrow mylonitic shear zones cutting the megacrystic diorite contain limonite staining and quartz veins.

h) Radiometric and Magnetic Characteristics

Table 2 summarizes the radiometric and qualitative magnetic characteristics of the main units in the complex. Total count radioactivity is low but correlative with potassic feldspar content. The magnetism corresponds well with the magnetite content seen in thin section. On the regional aeromagnetic map (Geological Survey of Canada, 1964), the Patterson Island gabbroic suite stands out as a magnetic high enclosed by the 4100 gamma contour. The peak above the 4400 gamma contour over Patterson Island coincides with the main body of megacrystic diorite; the syenomonzonite is reflected by corresponding troughs below 4000 gammas.

Table 3 – Modal Compositions (in Percent) of Supracrustals

	Rock Unit			
	Bmv[1]	*Bmv*[2]	*Qfa*[3]	*Qfa*[4]
K-feldspar	0-5	-	10-15	40
Plagioclase	7-60	-	15-25	5
Quartz	<1-10	-	35-50	50
Biotite	2-15	-	5-7	2
Chlorite	-	0-tr	-	tr
Phlogopite	-	0-15	-	-
Muscovite	-	-	-	<1
Hornblende	12-50	-	7-10	-
Actinolite	-	82[5]	-	-
Pyroxene	5-15[6]	<1	0-7	-
Carbonate	0-5	0-2	0-2	-
Epidote	-	0-tr	0-tr	-
Apatite	0-<1	tr	0-1	-
Opaque[7]	<1-2	tr-2	2-6	2
Zoisite	-	0-15	-	-
Gahnite	-	0-1	-	-
Sphalerite	-	0-tr	-	-
Olivine	-	0-<1	-	-
Garnet	-	-	-	<1
No. of sections	4	2	2	1

[1] hornblende-plagioclase amphibolite
[2] actinolite amphibolite
[3] feldspathic quartzite
[4] arkose
[5] tremolitic in one sample
[6] diopside in one sample
[7] magnetite or sulphide

3. Supracrustal and Associated Rocks

Table 3 shows the range of modal compositions.

Metavolcanics (unit Bmv) occur on the northwest corner of Patterson Island and form a narrow east-trending strip across the northern end of Wiley Peninsula. They are dark green weathering, dark green to black, very fine grained (0.5 to 1 mm) saccharoidal rocks locally possessing sparse 4 to 8 mm hornblende, plagioclase or pink potassic feldspar crystals in an equigranular groundmass of plagioclase, hornblende, pyroxene and biotite. A local variety comprises predominant actinolitic tremolite, minor phlogopite and zoisite. Minor carbonate, epidote and chlorite are typical alteration minerals. Traces of pyrite, pyrrhotite and chalcopyrite are present as disseminations and on fractures, some of which are heavily stained by limonite and contain abundant pyrite; the larger hornblende crystals commonly have pyrite rims. Actinolitic tremolite amphibolite near the Wiley Bay showing contains gahnite and sphalerite.

The rocks are weakly to strongly foliated, or locally massive and weakly compositionally layered on a 30 to 60 cm scale; these features may represent original flow layering. Concentrically zoned structures near the Wiley Bay showing may be former pillows. Contacts of the metavolcanics with adjacent rock units are sharp.

Angular amphibolite xenoliths set in felsic vein material are present in a few places. Massive varieties of the metavolcanics (unit Bmv) are similar to the amphibolitic xenoliths in the Patterson Island gabbroic suite. Silicified fractures, chloritic quartz pods and feldspathic veins, which in places form a network agmatizing the host rock, are all relatively common. On the northwest corner of Patterson Island, dykes, veins and 15 to 30 cm diameter pipes of syenomonzonite and micromonzonite, containing angular amphibolite xenoliths, invade and agmatize the metavolcanics.

Feldspathic quartzites and arkoses (unit Qfa) occur mostly as large areas of angular frost-heaved outcrop outlining narrow enclaves in the gabbroic suite west of Patterson Channel, and are associated with metavolcanics southwest of the Wiley Bay showing. The rock is grey to pink on fresh surfaces, rusty weathering, fine grained, equigranular and comprises predominant quartz, lesser plagioclase and potassic feldspar, with minor biotite, hornblende, pyroxene, epidote and carbonate. Some examples of feldspathic quartzite also contain up to 2 percent pyrite and 5 percent pyrrhotite; others are rich in calc-silicate and contain clots or bands of massive epidote. Arkosic varieties comprise quartz and potassic feldspar, and minor biotite, garnet and plagioclase.

Granite gneiss (unit Ggn) is present around the outer edge of the Patterson Island gabbroic suite and is closely associated with metasediments and metavolcanics west of Wiley Peninsula. The gneiss is pink weathering, grey, coarse grained, equigranular, strongly foliated gneissose and comprises quartz (30 percent), plagioclase (40 percent) and biotite (30 percent), and locally

Table 4 – Modal Compositions (in Percent) of Mafic Dyke and Sill Rocks

	Sample No.				
	0018	*0020*	*0022*	*0023*	*0054*
K-feldspar	-	-	-	-	<1
Plagioclase	50	-	15	22	33
Quartz	5	-	10	5	1
Biotite	8	-	-	10	12
Phlogopite	-	45	-	-	-
Muscovite	-	-	-	5	-
Hornblende	37	-	75	30	50
Pyroxene	-	48	-	<1	-
Epidote	-	-	-	25	-
Apatite	-	-	-	2	-
Opaque[1]	tr	7	<1	-	3

[1] magnetite or sulphide

contains rare 1 to 2 cm potassic feldspars. Angular 10 to 40 cm mafic inclusions are typical and may represent fragments of disrupted dykes rather than xenoliths. Submylonitic shears are present in places and the rock is locally cut by red aplitic dykes.

4. Mafic Dyke and Sill Rocks

Mafic dyke and sill rocks (unit dma) occur as 15 to 40 cm wide dykes and 30 to 40 cm thick sills cutting rocks of the Patterson Island gabbroic suite. Less commonly, the dykes range from 1 to 2 m and rarely up to 8 m wide. They are dark green to black, fine-grained, saccharoidal equigranular rocks having a wide range of composition (see Table 4), comprising predominant plagioclase and hornblende, and minor quartz. Less representative varieties contain phlogopite, pyroxene and epidote as major constituents.

Traces of disseminated pyrite and chalcopyrite and fracture-bound pyrite are present locally. Contacts vary from sharp and straight, with 2 to 20 cm wide vesicular chilled margins, to irregular and gradational, indicating post- and possibly syntectonic periods of intrusion. Posttectonic dykes, though narrow, persist along strike for distances of several hundred metres. The dykes show no preferred strike direction.

5. Structure

Foliation and layering within the Patterson Island gabbroic suite are generally parallel. The dips of primary igneous layering may be in part original and in part attributable to later folding. On Patterson Island, foliation and layering define a concentric arcuate pattern parallel to the western shoreline and dip towards a point on the east shore at progressively lower angles inland. East of the melagabbro/syenomonzonite contact, the foliation is reversed and dips steeply to the west or is vertical. Layering on the northern end of Wiley Peninsula dips alternately north and south in adjacent lithologic units, possibly indicating the presence of at least two folds with easterly-trending axes, one of which is responsible for infolding the metavolcanics.

Way-up evidence from igneous layering on Patterson Island indicates that the upper parts of the complex in this locality lie to the east, whereas, on the mainland where layering and foliation evidence is sparse or absent, the disposition of mafic to felsic units indicates that the upper, more felsic part of the western half of the complex lies to the west. The outcrop of the gabbroic units as several strips at intervals across Patterson Island probably reflects the presence of several differentiation cycles rather than repetition by folding.

Two major topographic lineaments cutting along the east and south coasts of Patterson Island probably represent faults along which there has been only minor displacement. A northerly-trending fault with an apparent sinistral displacement underlies the channel west of Wiley Peninsula. Northerly-trending arcuate lineaments on Patterson Island and south of Ant Lake are interpreted as the topographic expression of layering.

6. Economic Geology

Trench and core samples of metavolcanic-hosted disseminated pyrrhotite, pyrite and chalcopyrite from the Wiley Bay showing returned assays of 0.02 to 0.06 percent Cu, 0.01 to 0.09 percent Zn, 0.01 to 0.04 percent Ni, trace gold and 6.9 g/tonne (0.2 oz./ton) Ag over lengths of about 1.5 m. A northwest-trending graphitic shear breccia cuts the mineralized zone (Husky Oil Ltd., 1970). The author has identified zinc mineralization in the form of sphalerite and gahnite in thin section.

Lacana Exploration Inc. outlined an area of intensive hydrothermal alteration south of Ant Lake, where sulphide-PGM mineralization occurs in amphibole-lined fractures. Trench samples from a number of sites in the area returned maximum assay values of 0.58 to 1.48 percent Cu, 0.003 to 0.07 percent Ni, 91 to 4000 ppb Pd and 84 to 561 ppb Pt (Lacana Exploration Inc., 1986). Disseminated magmatic mineralization in the same area seldom exceeds 300 ppb combined Pt and Pd (Hulbert, 1987).

The sulphide-bearing metasediments in the area have a potential for base metal mineralization that has not been assessed. The potential of the megacrystic diorite for use as a decorative building stone deserves assessment.

7. Conclusions

Field evidence from the present study supports the hypothesis that the Patterson Island gabbroic suite is a cyclical cumulate-layered gabbroic-dioritic intrusion, and indicates that the megacrystic diorite ("the Patterson Island pluton") forms a layer within the complex rather than being a crosscutting late-stage intrusion. A general sequence of formation, from earlier mafic-rich pyroxenites through gabbros, diorites and monzonites to syenomonzonites, has been established by evidence from cognate xenolithic and crosscutting relationships. There is also evidence to suggest that the Patterson Island gabbroic suite is separated from the main body of the Swan River gabbroic rocks by a narrow enclave of supracrustals. The feldspathic quartzite and arkose components of the supracrustals are similar to banded calc-silicate quartzite (unit 9b) and meta-arkose (unit 18) in the Campbell River Group (MacDougall, 1987); however, diagnostic rock types such as the slatey argillite (unit 10a) and sulphidic mudstone (unit 11) were not located in the Patterson Island area, leaving the affinity of the arenaceous rocks in question.

8. References

Geological Survey of Canada (1964): Aeromagnetic map, Pearce Lake (NTS 64E-10); Geol. Surv. Can., Map 2746G, scale 1:63,360.

Hulbert, L. (1987): Geological environments for platinum group element mineralization - a brief overview; *in* Gilboys, C.F. and Vigrass, L.W. (eds.), Economic Minerals of Saskatchewan; Sask. Geol. Soc., Spec. Publ. 8, p33-36.

Husky Oil Ltd. (1970): Assessment File 64E10-SE-0005, Sask. Energy Mines, Regina.

Lacana Exploration Inc. (1986): Assessment File 64E-0009, Sask. Energy Mines, Regina.

Lewry, J.F., Roberts, K. and Rees, C.J. (1980): Geology of the area around Spalding Lake; Sask. Miner. Resour., Rep. 199, 18p.

Lewry, J.F., Thomas, D.J., Rees, C.J. and Roberts, K. (1981): Geology of an area around Compulsion Bay, Wollaston Lake; Sask. Miner. Resour., Rep. 205, 27p.

Macdonald, R. and Thomas, M.W. (1983): Compilation bedrock geology, Reindeer Lake north, NTS area 64E; Sask. Energy Mines, Rep. 232 (1:250,000 scale map with marginal notes).

MacDougall, D.G. (1987): Bedrock geological mapping, Campbell River area (part of NTS 64E-6); *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p34-45.

Potter, D. (1979): Investigations of basic igneous rocks, Peter Lake Domain; *in* Summary of Investigations 1979, Sask. Geol. Surv., Misc. Rep. 79-10, p56-60.

Ray, G.E. and Wanless, R.K. (1980): The age and geological history of the Wollaston, Peter Lake and Rottenstone domains in northern Saskatchewan; Can. J. Earth Sci., v17, p333-347.

Stauffer, M.R., Fumerton, S.L., Coleman, L.C., Mossman, D. and Langford, F.F. (1981): Geology of the Ballentin Island vicinity, Reindeer lake (part of NTS area 64E); Sask. Miner. Resour., Rep. 206, 22p.

Project 8833

Note on the Occurrence of Campbell River Group Metasediments Between Campbell Lake and Highway 902 (Parts of NTS Areas 64E-4 and -6)[1]

D. G. MacDougall

MacDougall, D.G. (1988): Note on the occurrence of Campbell River Group metasediments between Campbell Lake and Highway 902 (parts of NTS areas 64E-4 and -6); *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

The purpose of this project was to investigate areas within the 3500 gamma magnetic low (Geological Survey of Canada, 1964a, b) between Campbell Lake and Wathaman Bridge, where Campbell River Group metasediments, characterized by such regional magnetic lows, are likely to occur (MacDougall, 1987).

A small area was mapped within the magnetic low between Zacher Lake and the western end of Campbell Lake (Figure 1), which marks the southwesterly limit of known outcrop of the Campbell River Group.

Outcrop north and east of Zacher Lake and around the shoreline consists of fine-grained granite (unit 1c)[2] and tonalite (unit 4c); no evidence of metasediment was seen except small transported fragments in the glacial overburden. However, amphibolitic calc-silicate (unit 15c) is exposed at the northern outlet of Zacher Lake and in a steep ridge along the southeast side of the Campbell River. This rock is thought to be a facies equivalent of the banded calc-silicate quartzites (unit 9b) and is normally closely associated with the quartzite (unit 9a). Since the quartzites are known to occupy low ground along the shores of Campbell Lake and the Campbell River, it is possible that the large area of muskeg along the Campbell River and west of Zacher Lake is underlain by their continuation to the southwest.

Campbell River Group quartzites are also known at Kilometre 111 on Highway 902 north of Wathaman Bridge (Chance, pers. comm., 1987) where they occupy a partially muskeg-filled trough between ridges of Parker Lake Gneisses. The outcrop area falls within the 3500 gamma magnetic low (Figure 2). A road traverse southeast across the magnetic low failed to find any further occurrences; however, exposure is generally poor and there is ample scope for Campbell River Group to exist beneath other muskeg-filled depressions.

The Campbell River Group at Km 111 comprises grey quartzites, black siltstones/argillites and pink arkoses containing detrital grains of blue quartz. Blue quartz also occurs in some Parker Lake Gneisses, suggesting a possible provenance for the Campbell River sediments. The arkoses are finely banded and ripple marked and the quartzites show cross-bedding. The succession is right-way-up, strikes northeast and dips moderately steeply to both the northwest and southeast, possibly as a result of folding on subhorizontal northeasterly-trending axes, as in the Wollaston Domain. Near their northern contact, the quartzites are gritty and contain traces of disseminated malachite, chalcopyrite and pyrite. The adjacent Parker Lake Gneisses (Lewry et al., 1980) consist of dioritic (Gnd), monzonitic and granitic (Gna) gneisses and local amphibolite (Amp).

1. Discussion

Two features of the Campbell River Group are puzzling: 1) the abrupt change from predominantly euxinic mudstones and shales east of Campbell Lake, to a predominantly arenaceous, shallow water succession west of it; 2) its narrow lateral extent but great persistence along strike. Could the quartzites represent a former channel deposit subsequently folded into the basement along axes roughly corresponding to its former channels?

2. References

Geological Survey of Canada (1964a): Aeromagnetic map, Rutherford Lake (NTS area 64E-6); Geol. Surv. Can., Map 2761G (1:63,360 scale).

_________ (1964b): Aeromagnetic map, Robson Lake (NTS area 64E-4); Geol. Surv. Can., Map 2776G (1:63,360 scale).

Lewry, J.F., Roberts, K. and Rees, C.J. (1980): Geology of the area around Spalding Lake; Sask. Miner. Resour., Rep. 199, 18p.

MacDougall, D.G. (1987): Bedrock geological mapping, Campbell River area (part of NTS 64E-6); *in* Summary of Investigations 1987, Sask. Geol. Surv.; Misc. Rep. 87-4, p34-45.

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[1] Project funded under the Saskatchewan component of the Canada - Saskatchewan Subsidiary Agreement on Mineral Development 1984 - 89
[2] Unit numbering after MacDougall (1987)

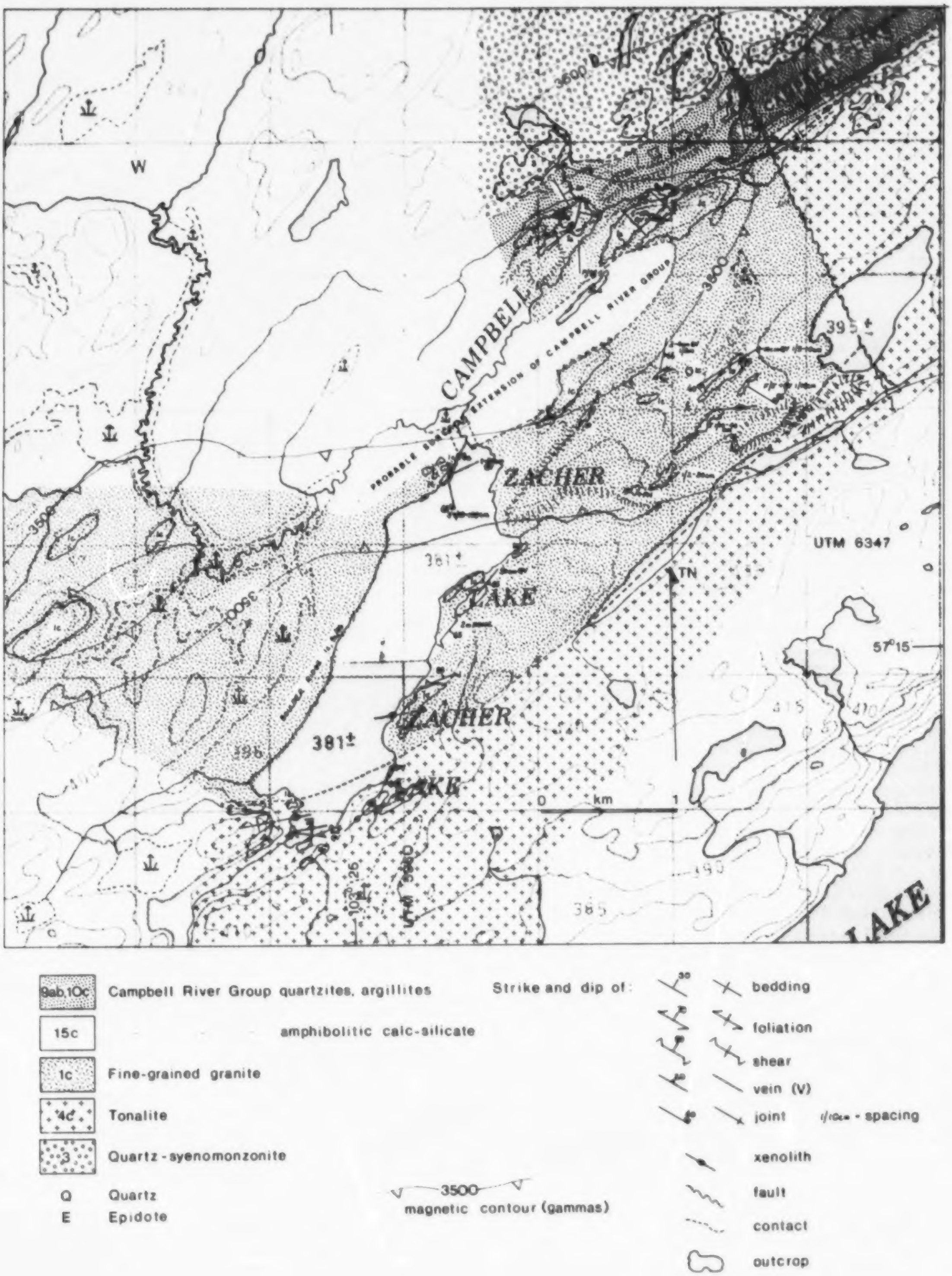
W
CAMPBELL
PROBABLE SOUTHWEST EXTENSION OF CAMPBELL RIVER GROUP
3600
3500
395±
ZACHER
LAKE
381±
ZACHER
LAKE
381±
UTM 6347
TN
57°15'
0 km 1
415
410
390
385
LAKE
9ab,10c
Campbell River Group quartzites, argillites
15c
amphibolitic calc-silicate
1c
Fine-grained granite
4c
Tonalite
3
Quartz-syenomonzonite
Q Quartz
E Epidote
3500
magnetic contour (gammas)
Strike and dip of:
bedding
foliation
shear
vein (V)
joint
1/10cm - spacing
xenolith
fault
contact
outcrop

Figure 1 – Campbell Lake-Zacher Lake area.

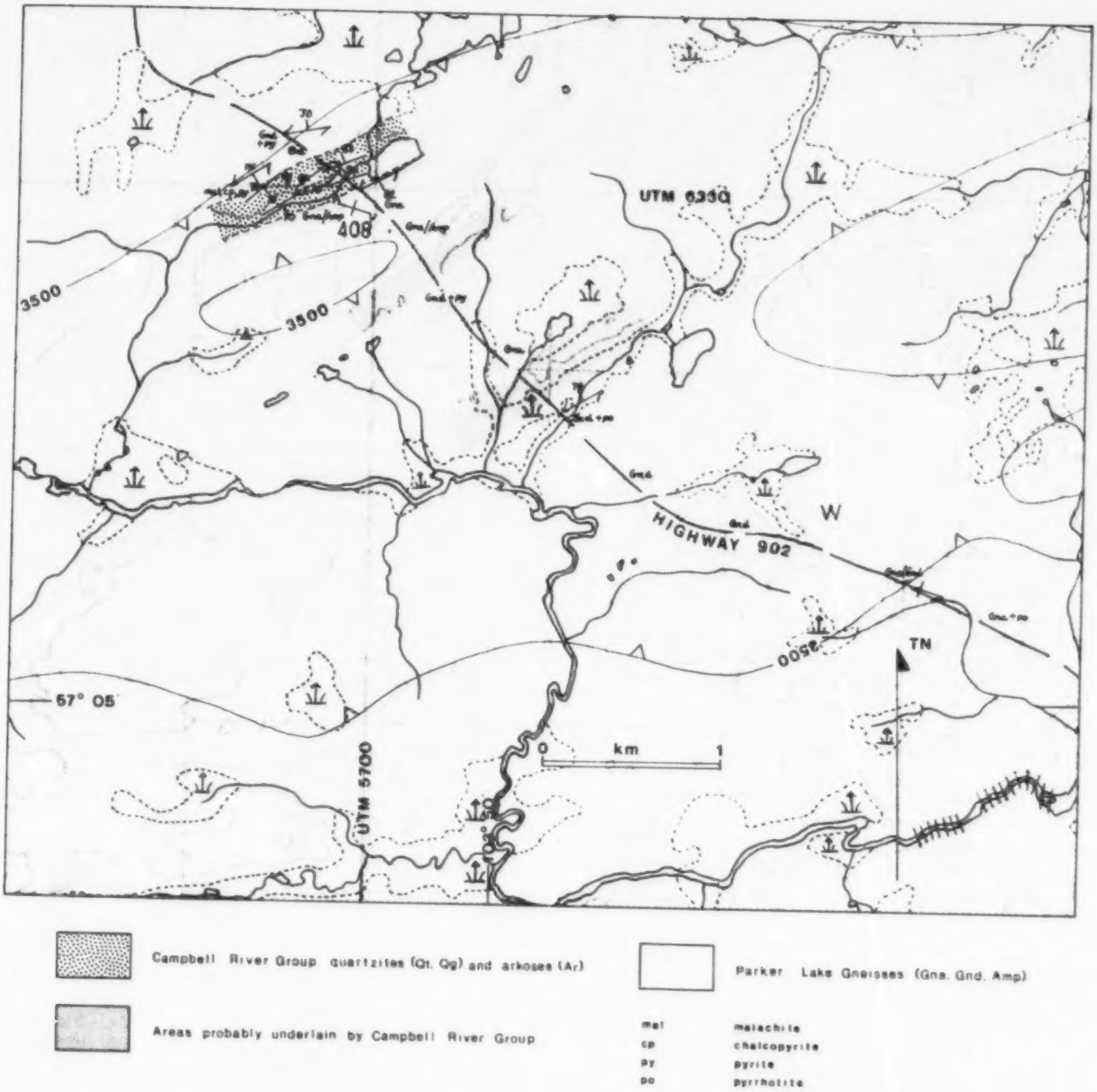
3500
408
UTM 6350
3500
HIGHWAY 902
W
TN
3500
57° 05'
0 km 1
UTM 5700
Campbell River Group quartzites (Qt, Qg) and arkoses (Ar)
Areas probably underlain by Campbell River Group
Parker Lake Gneisses (Gna, Gnd, Amp)
mal malachite
cp chalcopyrite
py pyrite
po pyrrhotite

Figure 2 – Occurrence of Campbell River Group along Highway 902 near Kilometre 111.

Project 8832

Geology and Geochemistry of the Uranium-Gold Mineralization in the Nicholson Bay – Fish Hook Bay Area[1]

E.P.W. Peiris[2] and G.R. Parslow[2]

Peiris, E.P.W. and Parslow, G.R. (1988): Geology and geochemistry of the uranium-gold mineralization in the Nicholson Bay – Fish Hook Bay area; *in* Summary of Investigations 1988; Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

A study of the uranium-gold mineralization in the Nicholson Bay – Fish Hook Bay area was begun last year as part of an M.Sc. program by the senior author (EPWP) at the University of Regina and reported upon in the 1987 Summary of Investigations (Peiris and Parslow, 1987). This report describes the progress of the study since that time. Some of the preliminary interpretations which are made here may be changed with further research.

1. Field Work Completed During 1988

Field work by the senior author covered three weeks in June and July of this year. Cores of eleven diamond-drill holes from the Nicholson no. 2 zone were logged and sampled for petrographic study; two of the cores (MCD 88-2 and 88-14) were sampled for later geochemical analysis. In addition, further surface mapping of the geology in and around the mineralized zones was carried out, resulting in the discovery of more outliers of Athabasca Group sandstones in the region. The presence of intense red staining and alteration in rocks adjacent to the unconformity precludes, in many instances, the ready discrimination between the Athabasca Group and the underlying basement quartzites.

Drill core was checked for possible uranium mineralization with a scintillometer, but significant radioactive zones were not detected. According to company drillhole logs and assay results, the gold mineralization is within the red zone; however, no obvious features distinguishing barren from mineralized sections of the drill cores were observed.

The two drillholes chosen for detailed geochemical sampling (MCD 88-2 and 88-14) are 38 m apart and plunge respectively at 55° and 50° on an azimuth of 115°. The red hematitic alteration zone extends from surface to 77 m depth in MCD 88-2 and from surface to 124 m depth in MCD 88-14 (Figures 1 and 2). Three mineralized sections are identified in MCD 88-2, with the highest gold assay (104,000 ppb or 3.33 oz./ton) encountered between 37.2 and 37.7 m; the other two mineralized sections occur from 62.4 to 66.1 m and 70.3 to 76.9 m. The company drillhole logs describe the MCD 88-14 core as essentially unmineralized (the highest gold assay is 320 ppb or 0.01 oz./ton at 119.1 to 120.1 m).

2. Petrography and Electron Probe Micro-Analyses

Petrography of selected surface and drill core samples from Nicholson Bay and Fish Hook Bay was performed during the year. The petrographic interpretations were checked and assisted by the electron probe micro-analyses carried out at the Natural History Museum in Vienna.

The probe data supported the petrographic identifications except in two cases: some euhedral crystals of gersdorffite turned out to be an arsenic pyrite and some skutterudite was actually bravoite.

Diopside, with ubiquitous tremolite, is abundant in the marbles, calc-silicates, and quartzites which are the dominant host rocks to mineralization in the area (Peiris and Parslow, 1987). The probe work identified talcose material, approaching anthophyllite in composition, as one of the alteration products of diopside in addition to talc and serpentine. Since talc is formed above 430°C to 470°C at 1 to 3 kb of pressure (Hyndman, 1972, p. 109) and serpentine is formed below these temperatures, the presence of talc may indicate an earlier(?) hydrothermal alteration of the calc-silicates. The calc-silicates were selected for the study of alteration because pure quartzites and marbles are insensitive to the alteration processes. Typical compositions of the diopside and its alteration products are given in Table 1.

The alteration processes tend to remove calcium totally, leach iron and enrich magnesium (see analyses Ta and An in Table 1). Diopside is pseudomorphed by a dark green or reddish, soft talcose mass. The development of the red variety is probably due to oxidation of any ferrous iron present, as the total iron contents of both the green and red "pseudomorphic diopside" are very similar. Within the hematitic zone, reddish-brown chert also pseudomorphs diopside. Additionally, chert and quartz replace carbonates, particularly in marbles.

Two different types of chlorites are found in fresh and altered rocks. Chlorites in the fresh marbles, interpreted

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(1) Project funded under the Saskatchewan component of the Canada – Saskatchewan Subsidiary Agreement on Mineral Development 1984 – 89

(2) Department of Geology, University of Regina

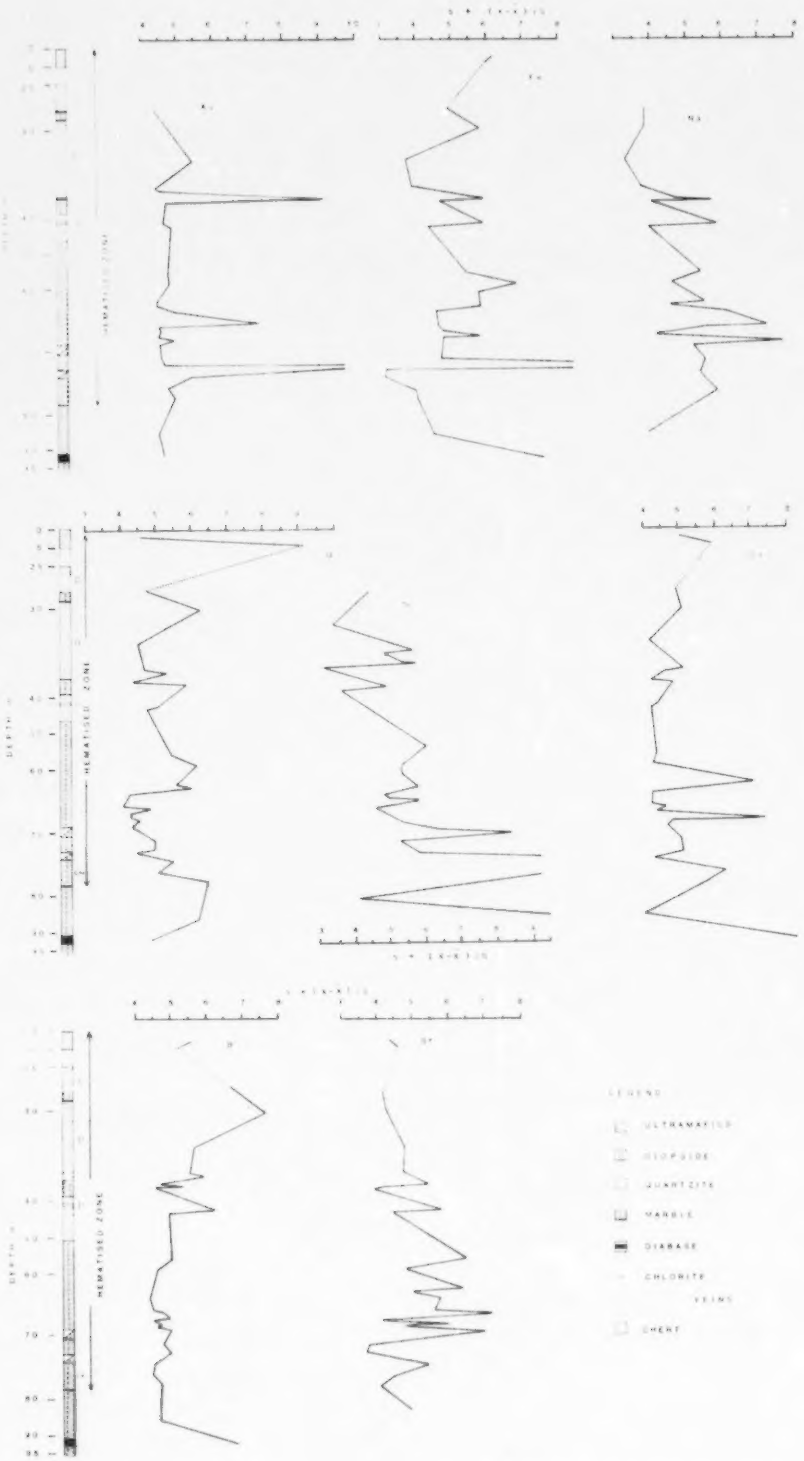

Figure 1 - Geology and variation of selected elements, drillhole MCD 88-2, Nicholson no. 2 zone. Probit scale used (Parslow, in prep.).

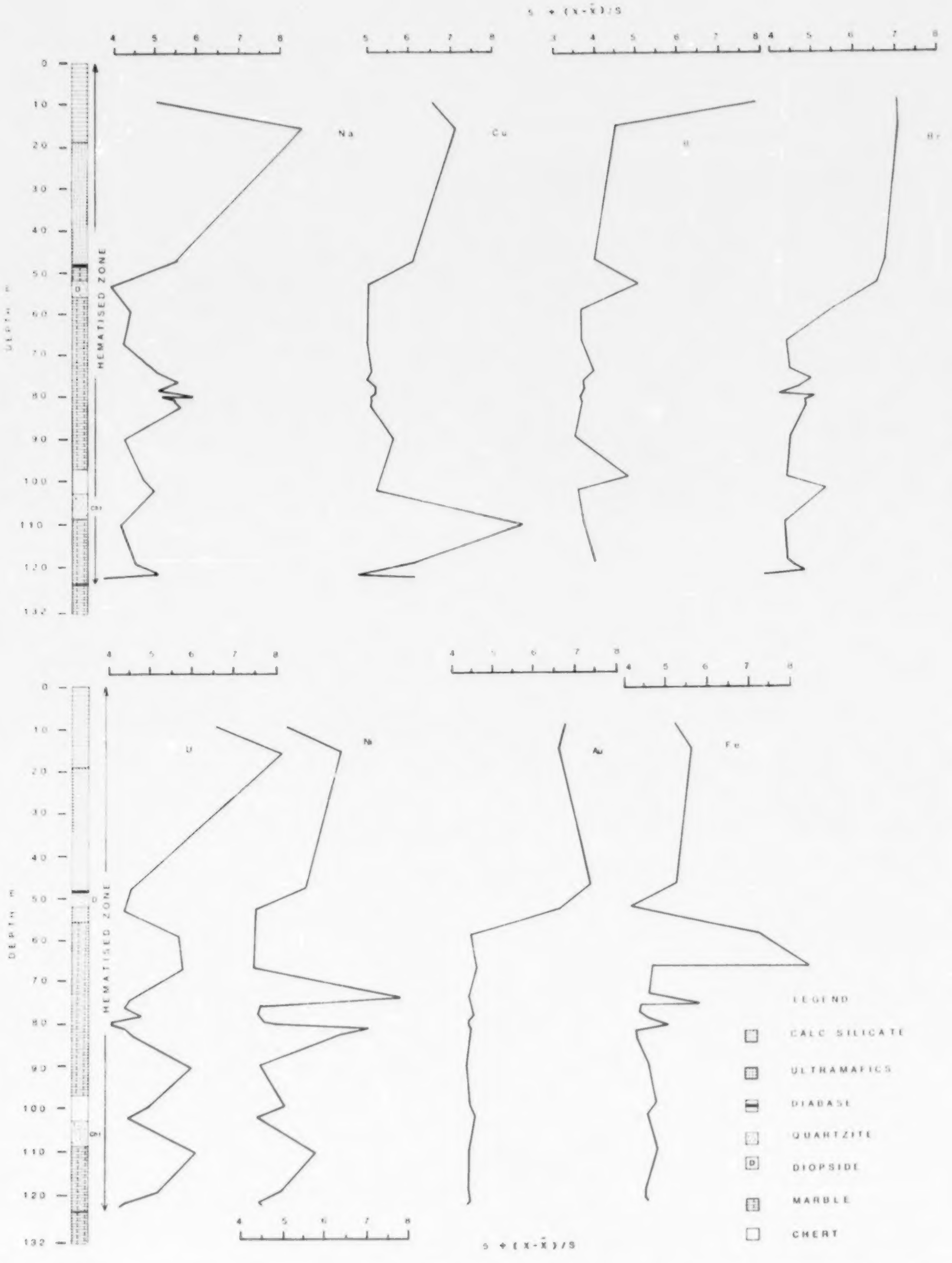

Figure 2 – Geology and variation of selected elements, drillhole MCD 88-14, Nicholson no. 2 zone. Probit scale used (Parslow, in prep.).

as products of the retrogressive metamorphism in the area, have a lower iron content than the chlorites penninite and pyrochlore associated with the mineralization within the red alteration zone.

Brecciation, which assisted in the development of permeability in the crystalline rocks, is evident and predates the introduction of the pitchblende veins.

In summary, the following *general* sequence of events can be inferred from the thin and polished sections:

1) Hydrothermal alteration of the host rocks characterized by pseudomorphic replacement of calc-silicate minerals.
2) Remobilization of pyrite, chalcopyrite and pyrrhotite into fractures, seen as veinlets within the "pseudodiopside".
3) Brecciation.
4) Introduction of euhedral carbonate and specular hematite as veins within the red alteration zone.
5) Formation of colloform pitchblende; veins commonly contain pyrite and chalcopyrite.
6) Development of rammelsbergite in cracks and voids in the pitchblende.
7) Formation of a second generation of pitchblende, emplaced along with colloform silica.
8) Formation of a second generation of rammelsbergite, with later niccolite filling cracks within the rammelsbergite.
9) Introduction of veins of gersdorffite, maucherite, skutterudite, bravoite, linnaeite, polydimite and millerite. The paragenetic sequence is complex, but is generally: gersdorffite, maucherite, polydimite and linnaeite. Bravoite and violarite are observed as alteration products of millerite. Euhedral grains of bravoitewith alternate pinkish-brown to brown zones were recognized by the probe analyses.
10) Finally, development of a second generation of green colloform silica very similar to that in stage 7.

Within the context of the above scheme, certain important problems of paragenesis remain unresolved:

Table 1 – Probe Analyses of Selected Minerals

	Di	*Tr*	*Ta*	*An*		*Pi*	*Pi*
SiO_2	55.1	58.7	63.6	64.1		1.53	11.1
Al_2O_3	0.14	0.08	0.01	0.08		–	–
TiO_2	0.01	0.0	0.02	0.0		0.0	0.3
FeO	3.6	5.3	2.48	1.83		3.2	0.36
MnO	0.9	0.68	0.0	0.05		–	–
CaO	25.0	13.4	0.02	0.02		2.81	2.91
MgO	16.1	21.1	29.3	29.8	PbO	1.35	0.3
Na_2O	0.03	0.0	0.03	0.03	ThO_2	0.0	0.0
K_2O	0.0	0.01	0.01	0.0	UO_2	80.98	70.0
Cr_2O_3	0.0	0.0	0.0	0.04			
NiO	0.0	–	0.02	0.03			
Total	100.88	99.27	95.49	95.94		89.87	84.74

Di, diopside; Tr, tremolite; Ta, talc; An, "anthophyllite"; Pi, pitchblende

1) Timing of gold introduction: Gold has been indicated by the electron probe within a grain of rammelsbergite and the senior author has tentatively identified tiny inclusions of gold within goethite in the red carbonate from high-grade sections of drillhole MCD 88-2. Thus, the gold may be associated with one or more of stages 4, 6 and 8 above.

2) Timing of hematite introduction: At least two generations of colloform hematite can be observed within the hematitic zone. Whether or not both generations of hematite belong to stage 4 is unknown at the present time.

3) Age of hydrocarbon "buttons": Hydrocarbon "buttons" are quite common in the wall rocks of the pitchblende veins. Pitchblende and arsenides fill cracks in the "buttons", suggesting that the mineralization is later than the organic material, but just how early the "buttons" are is not known.

4) Position of nolanite in the paragenetic sequence: Nolanite was identified in samples from the Nicholson no. 1 zone and in the Fish Hook Bay samples, forming pinkish to dark brown, hexagonal and strongly anisotropic crystals. Its position in the sequence is not known.

5) Position of bornite and chalcocite in the paragenetic sequence: Bornite and chalcocite are present in samples from the Nicholson no. 1 and no. 3 zones, and from Fish Hook Bay. They form up to 30 percent of the mineralization in the no. 3 zone. Their age is unknown but is presumably post stage 5.

Definition of possible chemical controls and age(s) of mineralization are fundamental factors in deposit modelling. Textures of the pitchblende, arsenides and sulphides typically indicate replacement of pyrite and euhedral carbonate. Goethite and hematite pseudomorphs of pyrite, and relict pyrite within these minerals, are common in the red marbles. Close by, chalcopyrite is commonly altered to native copper and covellite. Clearly, therefore, the oxidation of pyrite (stage 4) could have produced a reducing environment that determined the precipitation of later phases (stages 5 to 9).

The proximity of this basement-hosted mineralization to the sub-Athabasca Group Unconformity asserts the role of the unconformity and suggests two probable ages for mineralization: prior to and subsequent to deposition of the Athabasca Group. If mineralization is pre-Athabasca, then a paleoregolith origin is favoured; if it is post-Athabasca, an "unconformity-type" origin (as in the high-grade uranium deposits of the Athabasca Basin) is favoured The following evidence supports the latter:

1) Available discordant ages of pitchblendes from Nicholson indicate an oldest date of 1115 Ma (Koeppel, 1968), much younger than the depositional age of the Athabasca Group. Additionally, some of the probe analyses of pitchblende indi

cate virtually no Pb, reflecting a much more recent origin than even 1 Ga (compare the two pitchblende analyses in Table 1).

2) Chertification and growth of euhedral quartz and carbonate are observed in both the Athabasca sandstones and the basement alteration zones. The chertification is later than the authigenic syntaxial quartz overgrowths in the Athabasca sandstones; that is, post major diagenetic changes.

3) In the hematized sections in the basement (the 'red' zone), euhedral quartz and carbonate veins with specular hematite postdate the red alteration.

3. Geochemistry

Thirty-two samples from the MCD 88-2 and 20 samples from the MCD 88-14 were analyzed for their multi-element composition by Elemental Research Inc. of Vancouver. The samples were prepared for analysis in the geochemical laboratories at the University of Regina. Another 20 samples (mainly surface samples collected by T.I.I. Sibbald), comprising the different rock types found in the area, were also analyzed. The analyses were carried out using inductively coupled plasma mass spectrometry. Up to 63 elements were determined for each sample. Precision of the analytical method was checked by repeating every tenth sample. The following elements were generally below the detection limit of the method: As, Se, Rh, Cd, I, Te, Cs, Os, Ir, Re, Tl and Pt. Tungsten values are unreliable because of the possible contamination during the crushing process.

From the repeat analyses, it is clear that the technique defines most elements to a precision of ±10 percent, with the exception of Cr, Co, Mo, and Zr which often run to ±10 percent, and particularly B and Hg which exceed ±50 percent. In the time available, it proved impossible to obtain good standards covering the 63 elements; consequently, the accuracy of the ICPMS method is essentially unknown. On the other hand, the reasonable levels of precision allow the authors to draw the following conclusions:

1) As expected, the ultrabasic rocks and pelitic rocks have much higher concentrations of many trace elements than the quartzite, carbonate, calc-silicate and Athabasca sandstone samples.

2) Carbonate analyses can be grouped into 'fresh', 'slightly hematized' (light red in colour) and 'strongly hematized' (brick red in colour), approximating the trend: host rock to altered and in part mineralized zone. A comparison of elemental values, in fresh and altered rocks, indicates a definite increase in Co, Cu, Zn, Rb, Sr, Y, Nb, Pd, Ag, Cd, Ba, Ta, Au, Sb, Se and Ga with increasing hematization. It appears that Ni and Br are enhanced only in slightly hematized samples and that Sn is enhanced only in highly hematized samples. *Conspicuous by its absence in this correlation is the element U.*

3) Irrespective of these general trends, it is important to note that rarely does a given sample exhibit an enhancement of more than half the elements listed above. Thus, the elemental distributions 'controlled' by the increasing hematization are very erratic, as can be seen in the values of selected elements for samples from MCD 88-2 and MCD 88-14 (Figures 1 and 2). Strong and perfectly matching positive correlations of Au with other elements do not occur, only general correlations. *Uranium tends towards a negative correlation with Au.*

4) Although hematization of the altered rocks is visually impressive, total iron content remains essentially the same, suggesting that the 'red' zone was produced by a change in the oxidation state of the iron, rather than an introduction of iron. These data are shown in Figure 3 along with two samples of paleoregolith(?) which contain much more iron.

5) Although U does not correlate well with other elements in the hematized rocks (except perhaps negatively), two samples of pitchblende veins show strong enrichments of all the elements mentioned in (2), plus other elements such as As, Sc, Mo, etc.

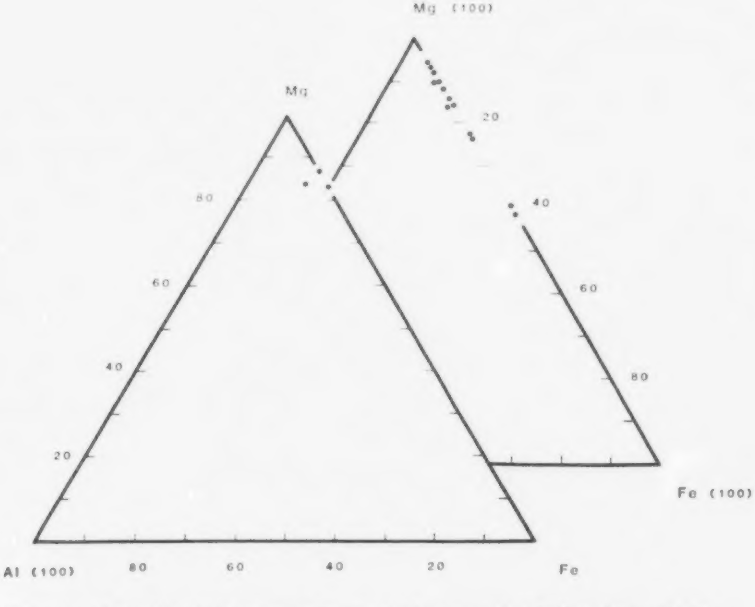

Figure 3 - Plot of Mg-Al-Fe ternary diagram for fresh marbles (left) and hematized marbles (right). Two points at 40 percent Fe on right are samples of paleoregolith(?).

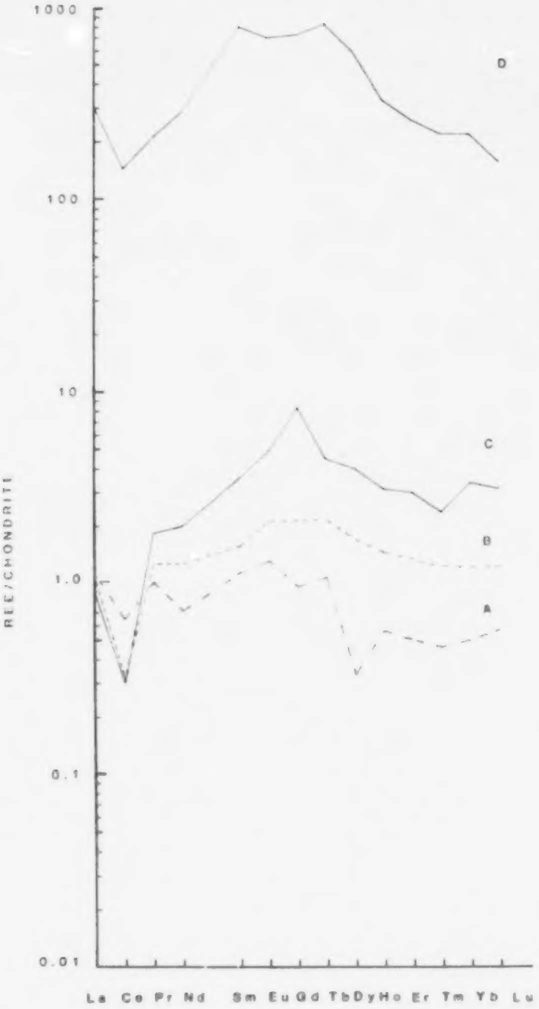

Figure 4 – Chondrite-normalized REE plots (averages of three analyses) for 'fresh' (A), 'slightly hematized' (B), and 'strongly hematized' (C) marbles. Trend D is an average of two pitchblende analyses.

Thus, a similar ore fluid to that controlling the Au mineralization is envisaged for the pitchblende vein formation.

6) Interpretation of the REE data is presently incomplete; however, some conclusions can be drawn from Figure 4, where the data for the 'fresh', 'slightly hematized' and 'strongly hematized' carbonates and pitchblende veins are compared. As hematization increases (A, B, C), the REE content increases and depletion of the lightest REE occurs; within the pitchblende veins, the total content of REE increases dramatically but the REE pattern is preserved.

7) The REE pattern for phosphorites or 'marine' apatites is essentially flat at an enrichment level of 2, relative to the average for North American shales. A similar plot of REE data for a sample of Athabasca sandstone containing 10+ percent apatite (not illustrated) shows a very strong depletion of the light REE. Thus, the apatites of the Athabasca Group are probably not of 'marine origin' and may represent an introduction of material as part of the mineralization process(?).

4. Conclusions and Implications for Exploration

1) Visual indicators of Au mineralization, in either surface or drill core samples, are not apparent other than an association with hematized rocks. Since large areas of the Beaverlodge region are 'reddened', this association is of limited use in detailed exploration studies (i.e., Nicholson Bay). Conversely, this observation suggests that the whole Beaverlodge area is worthy of further study for Au–PGE mineralization.

2) The fact that many veins of gangue minerals associated with the mineralization, as well as chert replacement features, are found in *both* the basement and the small outliers of Athabasca sandstones indicates a post-Athabasca age for the mineralization and a possible relationship with the unconformity.

3) The elemental associations of the Nicholson Bay mineralization are almost identical to those encountered in the 'unconformity-type' deposits of the Athabasca Basin, where U tends to be the dominant element in the association, although at Key Lake, U is subordinate to Ni in some parts of the ore. The authors conclude that an 'unconformity-type' model best explains the available data. The lack of clay alteration haloes is readily explained by the lack of feldspars in the country rocks.

4) Since graphitic pelites are not prevalent in the Nicholson Bay area, some other reductant process is required to form the observed mineralization. The common occurrence of pyrite and magnetite in the area and their destruction within the hematized and typically mineralized zones is a possible oxidation/reduction model that can be applied.

5) The generally negative correlation between U and Au in the hematitic alteration zone suggests either two periods of mineralization or, at least, a clear separation of these two elements within a single paragenetic sequence. It has been shown by Jaireth (1988) that Au and Pt can be transported with U in an oxidized saline fluid and thereby might be expected to be associated with U in unconformity-type deposits, at least from a thermodynamic viewpoint. However, at the present stage of research, the exact timing of Au introduction remains obscure.

6) Acceptance of the unconformity-related nature of the Nicholson Bay mineralization raises speculations about the exploration potential of other unconfor-

mities in the area such as those below the Martin Group and even the Thluicho Group.

5. Acknowledgements

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6. References

Hyndman, D.W. (1972): Petrology of Igneous and Metamorphic Rocks; McGraw-Hill, 533p.

Jaireth, S. (1988): Hydrothermal transport of platinum and gold *in* unconformity-related uranium deposits: a preliminary thermodynamic investigation; Record, Bur. Miner. Resour., Australia.

Koeppel, V. (1968): Age and history of the uranium mineralization of the Beaverlodge area, Saskatchewan; Geol. Surv. Can., Pap. 67-31, 111p.

Peiris, E.P.W. and Parslow, G.R. (1987): Metallogenic studies, Nicholson - Fish Hook Bays area; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p58-59.

Project 8832

Nicholson Bay Uranium – Gold – Platinum Group Element Deposit Studies[1]

T.I.I. Sibbald

Sibbald, T.I.I. (1988): Nicholson Bay uranium – gold – platinum group element deposit studies; *in* Summary of Investigations 1988; Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

The association of uranium with gold and platinum group elements was first reported at the Nicholson no. 2 zone prospect in the mineralogical studies of S.C. Robinson of the Geological Survey of Canada, published in 1955. Subsequently, in 1963, E.E.N. Smith of Eldorado found high gold and platinum values in pitchblende veins at the 45-SH-10 showing on Shirley Peninsula of Fish Hook Bay (Assessment File 74N08-0079)[2]. Until recently, these occurrences of gold and platinum group elements have been regarded as mineralogical curiosities.

A new impetus for exploration has been provided, however, by discovery of a potentially economic zone of gold – platinum group element mineralization adjacent to the Coronation Hill uranium deposit in the South Alligator River Uranium Field (SARUF) in the Northern Territory of Australia (Needham, 1987). Initial reserves of 800,000 t grading 5 g/t Au and values in Pd > Pt have been reported. Coronation Hill and other deposits in the SARUF show many similarities in mineralogy and geological setting to the Nicholson and Fish Hook Bay occurrences. The regional geological analogy is further enhanced by the resemblance of the nearby world-class unconformity-type uranium deposits of the Alligator River Uranium Field to those within the Athabasca Basin of Saskatchewan. New exploration at Nicholson, in areas adjacent to historic uranium occurrences, has found zones of gold and platinum group element mineralization not previously recognized. New discoveries of these metals have also been made elsewhere in the Beaverlodge – Goldfields area, in places where uranium occurrences are not known to exist.

1. Location and Previous Work

Nicholson Bay is located on the north shore of Lake Athabasca, some 18 km southwest of Uranium City and 4 km east of the historic townsite of Goldfields. The local geology has been mapped by the Geological Survey of Canada at scales as detailed as 1:4800 (Alcock, 1936; Joliffe, 1946; Christie, 1953) and at 1:20,000 scale by Saskatchewan Energy and Mines (Sibbald, 1982). In addition, parts of the area have been examined in great detail in connection with uranium exploration and mining developments since the mid-forties. Eldor Resources Limited and Mary Ellen Resources Limited currently operate exploration programs for gold and platinum group elements. Descriptions of the various mineral occurrences in the Nicholson Bay area have been provided by several authors (Christie, 1953; Robinson, 1955; Beck, 1969).

2. Objectives and Methodology

The present investigation involved a short field program designed to clarify possible controls on uranium – gold – platinum group element mineralization, particularly the role of the sub-Athabasca Group unconformity and tectonic structure. It was carried out in conjunction with detailed mineralogical and geochemical studies being undertaken at the University of Regina (Peiris and Parslow, this volume) and will be supported by stable isotope and fluid inclusion work at the University of Saskatchewn. The field program comprised:

1) 1:5000 scale mapping of the area surrounding Nicholson Bay, and
2) examination of outcrops and recently obtained Eldor and Mary Ellen drill cores of the mineral occurrences, in particular the Nicholson no. 2 zone.

3. Geological Setting

The Nicholson Bay area is underlain by the Murmac Bay Group, a presumed Lower Proterozoic shelf-type supracrustal sequence deposited on a 3.0 Ga basement (Van Schmus et al., 1986), which is exposed in the area to the northwest as the Lodge Bay Granite. The supracrustals are intruded and metasomatically replaced by granitic rocks which yield zircon ages of around 2.0 Ga and 2.35 Ga. These granitic rocks outcrop to the east and west, but not within Nicholson Bay itself, and are represented by the Box Mine Granite dated at 2.0 Ga and Athona Mine Granite and Mackintosh Bay Granite yielding the 2.35 Ga age (Van Schmus et al., 1986).

The supracrustal sequence at Nicholson Bay is a chaotic mixture dominated by white quartzites which grade into diopsidic quartzites, diopsidites and dolomitic marbles. The quartzites are locally rich in iron sulphides, particularly along the east shores of Nicholson Bay and Cornwall Bay. Cordierite-muscovite schist and quartz-eye muscovite schist form a subordinate part of the sequence, as do small units of amphibolite and biotite-

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[1] Project funded under the Canada – Saskatchewan Subsidiary Agreement on Mineral Development 1984 – 89

[2] Saskatchewan Energy and Mines Regina

quartz-feldspar schist (spotted biotite rocks). East of Nicholson Bay, a major outcrop area of metagabbro and serpentinized ultramafic rocks form the Nicholson Ultramafic Complex (Sibbald et al., 1983; Schwann, 1985). The complex is typically underlain by a thin, pyritic amphibolite unit exhibiting radiating fibrous amphibole (anthophyllite) which forms "bow tie" structures up to 3 cm in length. The amphibolite is intermixed with quartz-muscovite schists, suggesting possible derivation from a calcareous sediment rather than from marginal alteration of the ultramafic rocks.

Sandstones of the Middle Proterozoic Athabasca Group overlie the crystalline basement in a number of outliers west and north of Nicholson Bay. They are everywhere underlain by hematized altered rocks, typically "ferruginous quartzite and quartzite breccia" (Joliffe, 1946), which also appear to be intimately related to the zones of uranium, gold and PGE mineralization. It is not known whether diabase dykes, which locally intrude the basement, also cut the Athabasca Group.

The basement rocks at Nicholson Bay are influenced by two major deformation events and metamorphosed to lower-middle amphibolite facies grade. The metamorphic peak, attained after the first deformation (D_1), led to the development of annealed mineral fabrics, which were variably cataclasized and retrogressed by the second major structural event (D_2).

Shear zones were produced during both deformational events. In the Nicholson Ultramafic Complex, two gently to moderately westerly dipping D_1 shears, represented by ultramafic schists, cause repetition of the ultramafic-gabbro succession in an east to west direction. Upper gabbroic rocks are preserved in a series of "overthrust" outliers beneath the soles of the shears in the southern part of the complex. The interleaving of quartzites, carbonates and ultramafic rocks immediately to the north of Nicholson Bay probably also results from discrete D_1 shears.

D_2 folds are characterized by subvertical axial surfaces and gently south-plunging axes, and are parasitic to the Goldfields Syncline lying further west (Sibbald, 1984). The steep normal limbs of macrostructures are typically attenuated by shear zones parallel to the D_2 axial surfaces (S_2), as for example in outcrop-scale macrofolds exposed along the east shore of Nicholson Bay. Here, these structures have produced a major west-facing monoclinal flexure in the base of the ultramafic complex. The axis of this flexure passes through the Nicholson no. 2 zone. South of the no. 2 zone, sulphidic quartzites locally possess sulphide-quartz banding parallel to the S_2 fabric. Similar S_2 shears are reported in the Athona Mine area and are recognized as important in controlling gold-quartz veining (Roberts and Tyedmers, this volume).

Easterly-trending faults, with apparent left-lateral displacements, are the youngest significant discontinuities identified. One of these structures clearly displaces the Nicholson no. 4 pitchblende veins and alteration zone north of the mine workings.

The field program resulted in several new observations with respect to the Athabasca Group and the uranium-gold-platinum group element mineralization.

4. Athabasca Group

An outlier of the Athabasca Group was first identified by Sibbald (1982) on the west side of Nicholson Bay, where it overlies ferruginous quartzite and quartzite breccia. Between Nicholson Bay and Iron Cove of Cornwall Bay, several more small Athabasca outliers, also underlain by these basement rocks, have been recognized during the present study.

The sandstones and ferruginous quartzite outcrop at low to intermediate elevations, the tops of nearby hills being formed by unaltered basement. This would suggest the presence of local steep topographic gradients of the order of several tens of metres on the sub-Athabasca Group unconformity surface.

The Athabasca Group, which is probably no more than a few metres in exposed thickness, comprises poorly bedded to unbedded sandstones and breccias. The sandstones are pink to brown to grey and consist essentially of well-rounded and -sorted quartz grains coated by iron oxides and cemented by quartz. Grains are typically colourless to white, although a small proportion are of blue irridescent quartz. Single crystal grains predominate strongly over those formed by highly strained aggregates. In places, angular fragments of white quartzite up to several centimetres in size, resembling the adjacent basement quartzites, occur within the sand matrix. The sandstones locally appear to fill small fissures in the underlying basement quartzites. The textural features of these deposits suggest that the sands may be of eolian origin.

The Athabasca sandstones are cut by brown to red-brown ferruginous chert which occurs in veins, in zones of irregular replacement, and in nodules. In part, it encapsulates the angular quartzite fragments, suggesting preferential replacement along megaclast boundaries. Microscopically, replacement occured initially along quartz grain boundaries, replacing the quartz overgrowth cement, and then progressively corroded the matrix grains themselves, yielding a microcrystalline silica-iron oxide end product. Finely crystalline apatite occurs in one sandstone sample showing incipient chert replacement.

The ferruginous quartzites and quartzite breccias underlying the Athabasca Group are formed in part by cherty quartzite breccia containing angular relicts of white quartzite in a brown to red-brown cherty replacement matrix, and in part by hematitic white quartzite which is fractured and vuggy. The fractures and vugs are coated and filled by euhedral quartz, hematite (specularite) and yellowish-white euhedral carbonate. On both macroscopic and microscopic scales, it is apparent that pre-existing calc-silicate minerals (diopside with lesser amphibole) in the quartzites have been replaced by silica. In thin section, their shape and cleavage traces are outlined skeletally by opaque iron oxides which are set in a microcrystalline replacement aggregate of quartz.

Apatite has also been observed as part of this replacement assemblage.

Replacement is locally so pervasive that it is difficult to distinguish Athabasca sandstone from basement quartzite in the field.

5. Uranium-Gold-PGE Mineralization

Mineralization occurs in two main forms:

1) as discrete pitchblende veins exhibiting complex mineralogy and geochemistry, and
2) as irregular zones of gold-platinum group element concentrations.

The pitchblende veins contain a wide suite of ore minerals, including coffinite, Ni-Co arsenides and sulphides, native gold and silver. Common gangue minerals are carbonates, quartz and hematite. Amorphous carbon "buttons", typical of the paragenesis of unconformity-type uranium deposits in the Athabasca Basin, have also been identified in ore of the Nicholson no. 4 zone. Geochemically, the veins show concentrations of such elements as U, Cu, Ni, Co, As, Pb, Fe, V, Y, REE, Ag, Au and PGE (Table 1), although in any instance not all of these elements may be enriched. The veins primarily infill subvertical fractures, but the mineralization also shows some affinity for shallow-dipping lithological contacts. The veins occur close to the margins of major hematitic alteration zones (redox fronts), such as along the eastern margin of the Nicholson no. 2 zone and the western margins of the Nicholson no. 1, no. 1 extension and 4 zones, but on a detailed scale are discordant and may transect these margins. Examples of similar geochemically complex pitchblende veins are found away from major hematitic alteration zones in essentially unaltered basement rocks in other parts of the Beaverlodge-Goldfields area.

At the Nicholson no. 2 zone, gold-platinum group element mineralization occurs within the main body of hematitic alteration. Although anomalous values are widespread, economically significant values are restricted to discontinuous intersections in cores, suggesting the existence of irregular pods of "high grade". Sympathetically concentrated elements include Co, Cu, Zn, Rb, Sr, Y, Ag, Cd, Sb, Se and REE, but correlation is at best erratic (Peiris and Parslow, this volume).

To date, no morphological criteria have been presented to differentiate economically mineralized and essentially unmineralized core in the hematitic alteration zone.

The alteration surrounding mineralization shows similarities to that underlying the Athabasca Group. Although alteration is first manifest by steatitization of diopside prior to the appearance of hematite, the hematization is the most striking, varying in intensity to impart pink, red and earthy red-brown colours with increasing alteration. Other features of the alteration zones are: 1) hematitic chert replacing diopsidic quartzites (to produce ferruginous quartzite breccia) diopsidites and marbles; 2) development of vugginess and vug fillings of euhedral quartz, yellowish-white carbonate and specular hematite, particularly in quartzites and strongly hematized carbonates; and 3) veining by fibrous and euhedral yellowish-white carbonate. Hematization derives, at least in part, from replacement of pre-existing sulphides in the quartzitic and dolomitic host rocks.

Table 1 - Geochemistry of Pitchblende Veins, Nicholson and Fish Hook Bays

	Element Concentration (ppm)[1]											
Showing/Location	*Cu*	*Ni*	*Co*	*Zn*	*Pb*	*V*	*Y*	*Zr*	*Th*	*Ag*	*Au*	*U*
Joe/Fish Hook Bay	201	83	30	53	1204	319	109	53	41	4.2	21.5	3210
Joe/Fish Hook Bay	284	378	124	21	1776	209	207	81	45	3.5	0.12	4480
A/Fish Hook Bay	2100	352	132	64	509	8750	2644	561	89	1.3	0.28	6920
A/Fish Hook Bay	585	681	886	24	1626	397	696	181	429	8.7	0.27	31700
A/Fish Hook Bay	62	109	43	148	885	2094	334	92	78	4.7	0.20	5590
45-SH-10/Fish Hook Bay	274	52	31	26	3695	569	327	87	314	3.8	5.0	24900
45-SH-10/Fish Hook Bay	855	492	450	61	674	13700	254	118	133	18.4	1.0	9610
#1/Nicholson Bay	6850	41200	495	2143	1669	275	224	65	275	55.7	0.32	18300
#1/Nicholson Bay	80	51300	127	244	81	668	24	32	3	4.9	0.26	386
#2/Nicholson Bay	677	158	97	23	2667	718	113	51	119	9.5	36	8760
#2/Nicholson Bay	1350	50	21	84	5350	1663	568	147	687	89.3	96	46000
#3/Nicholson Bay	57000	123	19	144	101	2485	21	33	3	4.7	0.01	49
#3/Nicholson Bay	7600	1250	76	78	1151	1900	375	65	296	84.1	0.01	23200

[1] HF/HNO_3/$HClO_4$ digestion; Ni and Pb by atomic absorption; Au by MIBK extraction and atomic absorption, U by neutron activation/delayed neutron counting, all other elements by inductively coupled argon plasma spectrometry

There is presently insufficient drillhole and underground exploration information to allow the geometry of the alteration zones to be defined. Some relevent, but at this stage incomplete, observations are:

1) Hematitic alteration zones adjacent to mineralization are similar to, and have apparent continuity with, alteration underlying outliers of Athabasca Group sandstones.

2) Alteration extends to depths of at least 130 m at the Nicholson no. 2 zone and 95 m at the no. 4 zone. To the north of the no. 4 zone, exploration drilling (Assessment File 74N08-0106) across the northerly-trending valley joining the no. 4 zone workings to Iron Cove suggests a maximum depth of alteration of around 50 m, whereas to the south of the workings the alteration front rises abruptly to surface. There is no strike continuity with alteration zones surrounding the more southerly-lying no. 2 and no. 3 zones of mineralization.

3) Major structural controls other than those provided by the sub-Athabasca Group unconformity are enigmatic. Although pitchblende veins are clearly fracture controlled, margins of alteration zones are typically discordant to the most prominent joint directions. Alteration zones appear to pass into unaltered and undisturbed basement rocks along 'strike', suggesting the absence of any major fracture control.

6. Discussion

The existence of two distinct episodes of uranium mineralization in the Beaverlodge - Goldfields area, reflecting two entirely different episodes of metallogenesis, was first proposed by Hoeve and Sibbald (1978). Deposits of simple mineralogy, classically interpreted to be of Hudsonian metamorphic-hydrothermal origin (Beck, 1969), were formed about 1.75 Ga ago (Koeppel, 1968), whereas those of complex mineralogy are argued to have formed at essentially the same time as unconformity-type deposits in the Athabasca Basin. A variety of evidence can be assembled in support of the unconformity origin of the complex deposits, particularly those found at Nicholson and Fish Hook Bays, including:

1) proximity to the sub-Athabasca Group unconformity;
2) mineralogical and geochemical similarities to undisputed unconformity-type Athabasca Basin deposits;
3) U-Pb age data for pitchblende from Nicholson Bay which, although highly discordant, suggest an initial age of around 1.1 Ga (Koeppel, 1968); and
4) fluid inclusion data from gangue carbonate at Nicholson Bay, which indicate low temperature (150° - - 200°C) and high salinity "diagenetic fluids" similar to those characterizing unconformity-type Athabasca Basin deposits (Rees, unpublished data).

The new mapping has indicated an even closer spatial relationship than previously recognized between the sub-Athabasca Group unconformity and the Nicholson Bay mineralizations. Investigations of outcrop and drill core serve to exphasize the commonality of alteration processes occurring 1) above and below the sub-Athabasca Group unconformity, 2) adjacent to pitchblende veins containing gold and PGE, and 3) adjacent to pods of gold and PGE mineralization. The observation that replacement of the Athabasca Group by hematitic chert postdates quartz cementation is particularly important and suggests, in harmony with the fluid inclusion data, that alteration and presumably mineralizing fluids were oxidizing and diagenetic in nature. The ability of saline acidic oxidizing fluids (basinal brines) to transport geologically "realistic concentrations" of uranium, gold and platinum has recently been theoretically demonstrated (Jaireth, 1988).

From an exploration viewpoint, the "unconformity-type" model has several implications. Basement rocks proximal to the sub-Athabasca Group unconformity clearly are a high priority for exploration. Gold and PGE mineralization occurs apart from radioactive veins in the hematitic alteration zones, both at Nicholson and Coronation Hill. Exploration to date has been focussed for the most part around known uranium occurrences, leaving the potential of the much more extensive zones of hematitic alteration in the Nicholson - Fish Hook Bays area largely unevaluated.

In the area around Uranium City, the Athabasca Group overlies metamorphic basement and likely also overlies the immature clastics and mafic volcanics of the end-Hudsonian Martin Group. In the event that the aquifers of the Athabasca and Martin Basins were once connected, reducing environments in the Martin Group (e.g., the mafic volcanics at the Martin Lake Mine) and in the basement underlying the Martin Group (e.g., the graphitic argillites at the Lorado Mine) would provide potential sites for mineralization. It is significant in this regard that recent gold - PGE discoveries at Quartzite Ridge and east of Beaverlodge Lake are closely related to the sub-Martin Group unconformity.

Proximity to fluid source is a key element in deposit formation; hence, a finite depth extension to mineralization below the sub-Athabasca and sub-Martin unconformities is implied. Uranium mineralization at the Eagle Point deposit at Collins Bay has a depth extension of at least 365 m or about 400 to 450 m below the projected sub-Athabasca Group unconformity (Eldorado Resources Limited, 1987) and is among the deepest examples of unconformity mineralization presently recognized.

7. References

Alcock, F.J. (1936): Geology of the Lake Athabasca region, Saskatchewan; Geol. Surv. Can., Mem. 196, 41p.

Beck, L.S. (1969): Uranium deposits of the Athabasca region, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 126, 140p.

Christie, A.M. (1953): Goldfields - Martin Lake map-area, Saskatchewan; Geol. Surv. Can., Mem. 269, 126p.

Eldorado Resources Limited (1987): The Eagle Point uranium deposits, northern Saskatchewan; *in* Gilboy, C.F. and Vigrass, L.W. (eds.), Economic Minerals of Saskatchewan; Sask. Geol. Soc., Spec. Publ. 8, p78-98.

Hoeve, J. and Sibbald, T.I.I. (1978): On the genesis of Rabbit Lake and other unconformity-type uranium deposits in northern Saskatchewan, Canada; Econ. Geol., 73, p1450-1473.

Jaireth, S. (1988): Hydrothermal transport of platinum and gold in the unconformity-related uranium deposits: a preliminary thermodynamic investigation; Austral. Bur. Miner. Resour., Geol. Geophys. Record 1988/9.

Joliffe, A.W. (1946): Cornwall Bay–Fish Hook Bay area, Lake Athabasca, Saskatchewan; unpubl. map and report, Geol. Surv. Can.

Koeppel, V. (1968): Age and history of the uranium mineralization of the Beaverlodge area, Saskatchewan; Geol. Surv. Can., Pap. 67-31, 111p.

Needham, R.S. (1987): A review of mineralization in the South Alligator conservation zone; Austral. Bur. Miner. Resour., Geol. Geophy. Record 1987/52, 12p.

Robinson, S.C. (1955): Mineralogy of uranium deposits, Goldfields, Saskatchewan; Geol. Surv. Can., Bull. 31, 128p.

Schwann, P.L. (1985): Geochemistry and petrology of the Nicholson Bay Ultramafic Complex, northwestern Saskatchewan; unpubl. B.Sc. thesis, Univ. Regina, 67p.

Sibbald, T.I.I. (1982): Uranium metallogenic studies, Nicholson Bay area; *in* Summary of Investigations 1982, Sask. Geol. Surv., Misc. Rep. 82-4, p43-45.

________ (1984): Gold metallogenic studies, Goldfields area; *in* Summary of Investigations 1984, Sask. Geol. Surv., Misc. Rep. 84-4, p116-121.

Sibbald, T.I.I., Schwann, P.L. and Dunn, C.E. (1983): Uranium–gold metallogenic studies: Nicholson Bay Ultramafic Complex; *in* Summary of Investigations 1983, Sask. Geol. Surv., Misc. Rep. 83-4, p75-79.

Van Schmus, W.R., Persons, S.S., Macdonald, R. and Sibbald, T.I.I. (1986): Preliminary results from U-Pb zircon geochronology of the Uranium City region; *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep. 86-4, p108-111.

Project 8806

Structural Controls of the Box and Athona Deposits, Goldfields, Saskatchewan: Progress Report[1]

R.G. Roberts[2] and P.H. Tyedmers[2]

Roberts, R.G. and Tyedmers, P.H. (1988): Structural controls of the Box and Athona deposits, Goldfields, Saskatchewan: progress report; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

The objective of the project is to establish the structural controls of the Box and Athona gold deposits in the Goldfields district on the north shore of Lake Athabasca. The deposits were mapped in June and July 1988, at a scale of 1:1,000.

The following brief description of the geology of the district and the deposits is taken from Sibbald (1984) and Sibbald and Jiricka (1986).

The region is underlain by Lower Proterozoic shelf-type sediments, metamorphosed to lower amphibolite facies. Conformable andsubconformable amphibolite bodies, up to a few tens of metres thick and of probable igneous origin, occur within the sequence. The most abundant rock type in the area is granite, which occurs in a variety of textural and structural types (Sibbald and Jiricka, 1986). For the purposes of this report, the granites may be considered to fall into two groups: 1) foliated granites in which the foliation of the earliest deformation is well represented; and 2) non-foliated or weakly foliated granites in which the earliest foliation is only poorly developed or not developed at all. The granites hosting the Box and Athona deposits (the "Mine Granites") fall into the latter group.

Two periods of deformation are recognized in the area. The first deformation is associated with the development of a foliation (S_1), which is parallel or subparallel to the compositional layering of the metasediments. This foliation is defined by the preferred orientation of micas, amphiboles, chlorite and aggregates of quartz and feldspar. The second deformation is manifest in the folding of the compositional layers and the earlier S_1 foliation. The Goldfields Syncline is a major structure formed during this period of deformation (Sibbald, 1984). The syncline is an upright open fold, plunging between 15° and 20° to the south.

The Box Mine lies on the western limb of the structure and the Athona near the axial surface trace of the fold. The ore of both deposits consists of gold-bearing quartz veins in lenticular units of "Mine Granite". The structural evidence indicates that the veins were emplaced during the second period of deformation.

The relationship of the gold-bearing vein system to the second period of deformation and the formation of the Goldfields Syncline is best illustrated by structural features at the Athona. The Athona "Mine Granite" occurs at the closure of the syncline, defined by the S_1 fabric in the underlying foliated granite, and in conformable units of amphibolite. An S_2 fabric, which is geometrically related to the syncline, is developed in the amphibolite units and in the "Mine Granite". In the amphibolite, S_2 consists of ductile shears, which vary from penetrative shears with strike lengths of a few centimetres to shear zones of the order of a metre wide and strike lengths up to 200 m. The shears strike between 358° and 030° and, for the most part, dip subvertically east and west. S-C fabrics in the shears indicate both left- and right-hand movement in the horizontal plane, but there appears to be no relationship between the attitude of a shear and its sense of movement. The lineations formed by the intersection of the S-fabrics and C-fabrics plunge to the south at approximately 20°.

The north-south contacts of amphibolite with "Mine Granite" are shear contacts. However, with the exception of a shear that runs along the east shore of the Athona peninsula, and which probably has a reverse movement of some tens of metres, the displacement on the shears is not significant.

The ductile shears in the amphibolites are represented in the Athona "Mine Granite" by brittle-ductile shears with the same attitude. The gold-bearing quartz veins are emplaced along these shears and in related secondary shears. The mineralization of the "East Zone" is in the zone of high strain along the east shore of the Athona peninsula referred to above. The mineralization of the "Main Zone" can probably be related to brittle-ductile shearing developed at a minor anticlinal flexure in the syncline.

Brittle-ductile shears with quartz veins occur in the underlying foliated granite but are not gold bearing. Quartz veins do not occur in the ductile shears of the amphibolite.

The relationship of the veins at the Box Mine to the formation of the Goldfields Syncline is less obvious. The principal gold-bearing quartz veins strike between 345° and 020° and dip between vertical and steeply to the west. The veins are of the order of 10 cm thick and persist along strike for probably as much as 15 m. They

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[1] Project funded under the Saskatchewan component of the Canada - Saskatchewan Subsidiary Agreement on Mineral Development 1984 - 89

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are not directly associated with shear structures and their internal structure is indicative of tension crack filling.

Shearing is developed locally in zones along the hanging wall and footwall contacts of the Box deposit. In the footwall, the contact is generally with quartzofeldspathic rocks, and in the hanging wall with amphibole-chlorite schists. The shearing is parallel to the contacts and, according to kinematic indicators, directed to the southwest. Lenticular quartz veins, conformable with the shears, occur; however, available data indicates that the veins do not contain economic concentrations of gold. The gold-bearing north-south veins cut the conformable veins and in some locations pass into them. Similar zones of shearing occur at Athona, at the shallow dipping contact surfaces of amphibolites and "Mine Granite". Most of the deformation is confined to the amphibolite. The shearing is probably related to the early stages of folding during the second deformation; however, the mechanical significance of the Box veins has not been established.

At both the Box and the Athona deposits, the youngest veins are steeply dipping breccia veins contained in tabular zones, up to a metre wide, of brecciated wall rock in a vein-quartz matrix. The veins contain specular hematite in places and are generally surrounded by a halo of hematized "Mine Granite" in which pyrite is replaced by hematite. A fracture set coplanar with the breccia veins, and generally associated with the breccia veins, occurs in the Box deposit. Locally, the fractures are mineralized with hematite, and in some of these pitchblende is also present in veins up to 3 mm wide. Zones of such fractures may be up to 1.5 m wide. Where the mineralized fractures intersect the earlier north-south veins, pyrite in the quartz veins is altered to hematite, and the gold content is substantially greater.

References

Sibbald, T.I.I. (1984): Gold metallogenic studies: Goldfields area; *in* Summary of Investigations 1984, Sask. Geol. Surv., Misc. Rep. 84-4, p116-121.

Sibbald, T.I.I. and Jiricka, D.E. (1986): Geology of the gold deposits, Goldfields, Saskatchewan; *in* Clark, L.A. (ed.), Gold in the Western Shield; Can. Inst. Min. Metall., Spec. Vol. 38, p412-414.

Project 8804

Geology of Early Proterozoic Gneissic Rocks, Black Birch Lake Area[1]

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Orrell, S.E., Tangeman, J.A. and Bickord, M.E. (1988): Geology of Early Proterozoic gneissic rocks, Black Birch Lake area; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

Precambrian rock exposures in the Black Birch Lake area were mapped in June through August of 1988 as part of the Snowbird Transect Project, a joint venture involving the Saskatchewan Geological Survey and the University of Kansas. The work will also be the basis for the senior author's dissertation research. The ultimate purpose of the project is to constrain tectonic and crustal evolution models for the Mudjatik Domain of the Trans-Hudson Orogen, as a basis for metallogenic modelling amongst other things. The work will include major and trace element and isotopic studies of whole rocks, minerals and fluid inclusions.

The Black Birch Lake area was mapped previously at 1:100,000 reconnaissance scale by Sibbald (1973). The geology of Black Birch Lake is also shown at a scale of 1:250,000 on the compilation map of Thomas (1984). In the current study, field work was concentrated on a subarea which was burned since the field work for the previous study was completed. The bulk of this field season's area was mapped at a scale of 1:20,000 (Figure 1), and one very small area (200 m^2) was mapped at a scale of 1:500 by Tangeman (Figure 2).

1. Geological Setting

Black Birch Lake lies within the Cree Lake Zone of the Churchill Platform (Van Schmus et al., 1987; Lewry and Sibbald, 1977). The Cree Lake Zone is further divided into a number of lithotectonic domains; Black Birch Lake is within the Mudjatik Domain. In contrast to the neighbouring Virgin River and Wollaston Domains, the Mudjatik Domain is characterized by nonlinear structural trends defined by outcrop pattern, foliation and compositional layering in (possibly polymetamorphic) upper amphibolite to granulite facies transition gneisses (Lewry and Sibbald, 1977). These rocks have been divided previously into an inhomogeneous package of variably tonalitic to granitic gneisses (the Mudjatik "felsic gneisses") and a volumetrically subordinate package of gneisses of probable supracrustal origin (Lewry and Sibbald, 1977, 1980). On the basis of its highly tectonized and mobilized nature, the Mudjatik Domain is thought to have been reactivated during the Trans-Hudson Orogeny; there is, however, only preliminary radiometric evidence to substantiate this so far (see Bickford and others, this volume).

2. Summary of Lithology

The granitic gneisses of Lewry and Sibbald (1977) have been divided by the authors into three units: 1) tonalitic to trondjhemitic gneisses, which probably represent the oldest group, 2) layered granitic augen gneisses, and 3) fine-grained biotite leucogranite. The tonalitic gneisses are variably layered and were probably intruded by a protolith of the layered augen gneiss; unequivocal crosscutting relations were not observed in the Black Birch Lake study area, but were identified in the adjacent Ithingo Lake area (C.T. Harper, pers. comm., 1988). The fine-grained leucogranite, which is incipiently foliated, intrudes both the tonalitic gneisses and the granitic augen gneiss, as well as supracrustal units, as slightly discordant, metre-wide apophyses, lenses and sheets.

Rocks of probable supracrustal origin distinguished this summer are similar to those mapped by Lewry and Sibbald (unpublished). Lewry and Sibbald's mafic unit has, however, been divided into three new units. In structural order from the base above the tonalitic and augen gneisses these are:

8) felsic gneisses (possibly metavolcanics), including probable metasedimentary (arkosic) components.
7) mafic to intermediate metavolcanic rocks, with discontinuous interlayered meta-arkoses; and
6) pelitic gneisses;
5) psammitic to pelitic gneisses, including layered quartzites;
4) metavolcanic rocks with possible mafic metatuffs, and garnetiferous anatectites;
3) psammitic to psammopelitic gneisses;
2) metabasalt;
1) psammitic gneisses (at the base);

Volumetrically minor pegmatite dykes are slightly deformed and typically cut compositional layering of country rocks at low angles.

Lateral lithofacies variation is suspected within the supracustal rocks. This is particularly noticeable in the major pelitic unit, which in some localities is a well-defined, strongly layered and highly aluminous rock, whereas in other localities along strike of foliation, it is less well defined, poorly banded and less aluminous. This apparent lithologic variation may, on the other

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(1) Field support provided under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89, in joint venture with the University of Kansas

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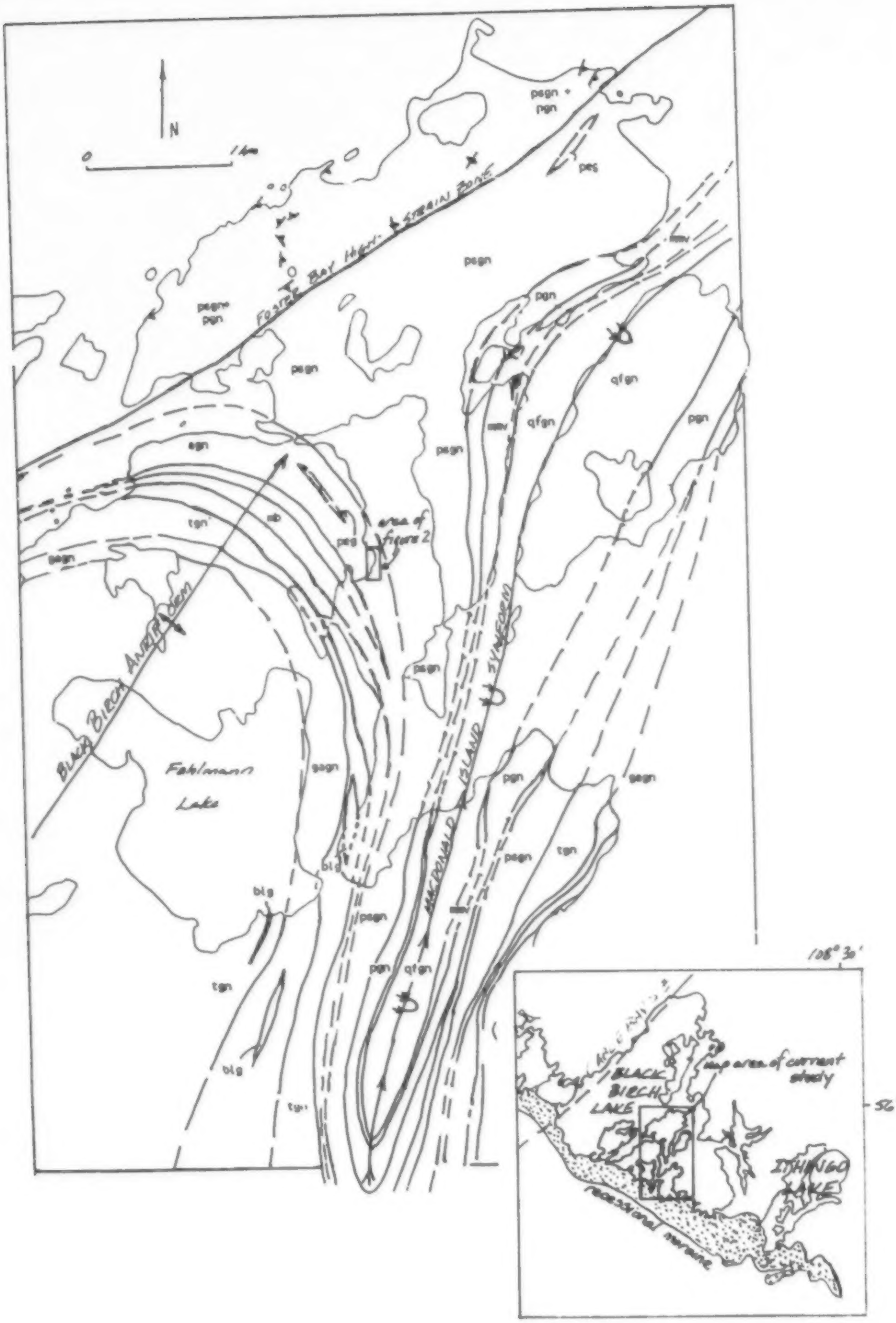
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BLACK BIRCH ANTIFORM
MACDONALD ISLAND SYNFORM
Fahlmann Lake
blg
108°30'
56°55'
BLACK BIRCH LAKE
map area of current study
ITHINGO LAKE
recessional moraine

Figure 1 – Sketch map of geology of south-central Black Birch Lake area. Symbols: tgn, tonalitic gneisses; gagn, granitic augen gneisses; blg, biotite leucogranite; peg, peraluminous and metaluminous pegmatite; psgn, psammitic gneisses; pgn, pelitic gneisses; mb, metabasalts; agn, amphibolite gneisses; mmv, mafic metavolcanics; qfgn, quartzofeldspathic gneisses.

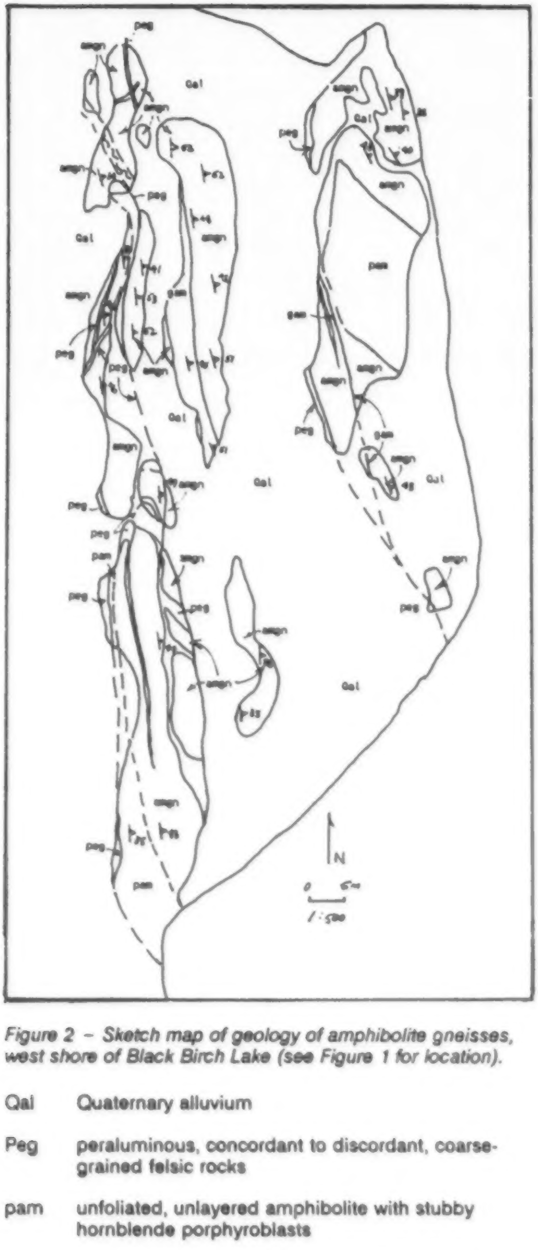

Figure 2 - Sketch map of geology of amphibolite gneisses, west shore of Black Birch Lake (see Figure 1 for location).

Qal	Quaternary alluvium
Peg	peraluminous, concordant to discordant, coarse-grained felsic rocks
pam	unfoliated, unlayered amphibolite with stubby hornblende porphyroblasts
gam	concordant layer of finely laminated garnetiferous amphibolite, associated with rusty-weathering sulphide-rich zones
amgn	finely laminated, medium-grained hornblende amphibolite gneiss, with volumetrically subordinate calc-silicate layers
∿∿	shear zone
— - -	lithological contact (dashed where approximate)
⊬34	strike and dip of foliation

hand, be wholly or in part due to inhomogeneous deformation and anatexis. Observed lateral variations of the mafic and arkosic units may be explained similarly.

Migmatitic units have typical neosomal mineral assemblages. Neosomes in psammitic gneisses are commonly peraluminous (cordierite ± garnet ± biotite ± sillimanite), whereas neosomes in tonalitic gneisses are commonly metaluminous (hornblende, hornblende + biotite, biotite), suggesting that much of the neosomal material is derived locally by partial melting. Variable neosome/paleosome ratios were observed, especially in psammitic gneisses. Where the neosome forms more than 30 percent of the rock, there is a loss of structural coherence and the apparent production of localized agmatite. Well-developed agmatite was observed, in fact, at only one locality. Here the rocks are characterized by large, disoriented, subangular to angular blocks of layered psammitic gneiss a metre or so in size which are set in a granitic to pegmatitic matrix.

3. Structural Geology

Regional structures in the area are defined by compositional layering. The largest structures are the northeasterly-plunging Black Birch Antiform, and the adjacent MacDonald Island Synform to the southeast which has a more northerly plunge (Figure 1).

The Black Birch Antiform is an approximately symmetrical upright fold with a vertical to subvertical axial surface, and a northeasterly plunge of approximately 45°. The hinge zone represented on the geological map and in Figure 1 has an apparently open form, although it has not been traced out fully on the ground.

The MacDonald Island Synform is tightly compressed and overturned westwards towards the Black Birch Antiform.

A zone of apparent high strain, the Foster Bay High Strain Zone, has been inferred from structural trends to trace northeastwards across Foster Bay, where it apparently transects higher structural levels across the nose of the Black Birch Antiform.

a) Regional Tectonic Foliation

Most rocks in the area are granoblastic and mineral foliations are rare. An exception to this is seen in some pelites, where biotite and fibrous or prismatic sillimanite lie parallel to the foliation, banding or lithological layering.

The regional compositional layering appears to predate all observed folding, and defines all small-scale folds. Excluding the leucogranite and the (possibly late) pegmatites, all units are layered to some extent, and many units are layered at all scales. Much of the centimetre to tens of centimetres scale layering is related to nearly ubiquitous (possibly anatectic) migmatization. Metre-scale and thicker layering may, on the other hand, be related to older lithologic inhomogeneities. Inhomogeneous deformation also apparently served to intensify preexisting compositional layering, notably in some of the mafic metavolcanics. Details of layering in individual units is described later.

b) Lithological Contacts

From observations of the parallelism of compositional layering, mineral foliation and lithological contacts, lithological contacts in the study area are considered to be tectonically transposed. In two localities, discordance in foliation between lithological units may be explained by slip along the contacts.

c) Folds

The regional tectonic foliation and associated mesoscopic isoclinal folds are deformed by at least two other fold sets. First foliation (F_1) and possibly second-generation (F_2) folds can be identified at outcrop scale, but possible third-generation folds (F_3) are defined by outcrop patterns. Pending further study, all three fold systems are assumed to have been generated during one progressive deformational event.

F_1 Folds:

The earliest formed folds recognized consist of mesoscopic isoclinal folds with axial planes lying parallel to foliation. Such folds are seen in all units except the augen gneiss and leucogranite, but are best and most profusely developed in the mafic to intermediate volcanics. In the mafic to intermediate volcanic rocks (unit 7, Table 1), the ratio of amplitude to wavelength is typically on the order of 10:1, with wavelengths of centimetres to tens of centimetres. Folds of this size and orientation occurring in the mafic metavolcanic rocks are associated with abundant and very small rootless isoclines ("fishhooks"), with a half wavelength of less than 1 cm, defined by quartz stringers. The axial planes of the mesoscopic isoclinal folds commonly strike moderately northeast and dip moderately to the southeast.

The mesoscopic F_1 folds are probably related to the early megascopic recumbent folds which placed the supracrustal sequence at variable structural levels in the Mudjatik Domain (Lewry and Sibbald, 1977). The MacDonald Island Synform, a large overturned tight asymmetric synform in the eastern part of the area may be one of these earlier megascopic folds. The axis of this synform plunges to the north, probably at a shallow angle, and the axial plane strikes north-northeast and dips steeply to the southeast.

F_2 Folds:

Possible second-generation folds recognizable at outcrop scale are much rarer than the first-generation folds. These possible F_2 folds are generally asymmetric and much more open than the F_1 folds (Figure 3), and the axial planes strike moderately northwest and typically dip steeply to the northeast. In the mafic metavolcanics, possible F_2 fold axial planes lie subparallel to small (1 to 5 mm wide) quartz + plagioclase + chlorite veins. These veins have a minimum spacing about 40 cm, and at least some of them have accommodated slip, as in many instances compositional layering cannot be traced across the veins.

Possible F_3 Fold:

The regional-scale Black Birch Antiform, which is defined at low structural levels by compositional layering, may be a product of third-generation folding.

d) Mineral Lineation

Mineral lineations have been observed on the west limb of the MacDonald Island Synform in the south-central part of the study area, and were most commonly encountered on foliation surfaces in the felsic and mafic to intermediate metavolcanic rocks. The lineation is most commonly defined in the mafic metavolcanic rocks by the parallel alignment of hornblende grains, and in the felsic metavolcanic rocks by parallel alignment of elongate streaks of medium-grained biotite. These mineral lineations do not typically lie parallel to the F_1 fold recorded nearby, or to the axes of major folds deduced from map patterns.

e) Secondary Cleavage

A north-striking, steeply dipping secondary cleavage (Figure 4) was recognized in a few outcrops of psammitic gneiss and tonalitic gneiss in the central part of the study area. This cleavage consists of spaced zones of finite width, spatially associated with the thinned steep limbs of asymetric harmonic folds. The spacing of these cleavage zones varies from 2 to 30 cm, with an average of about 25 cm. The width of individual zones varies varies from much less than 1 cm to about 5 cm; the widest appear to contain aplite or granite probably derived by recrystallization of country rock. Many cleavage zones have truncated and offset the preexisting layering. All unequivocally observed offsets are left-lateral, with apparent offsets ranging from less than

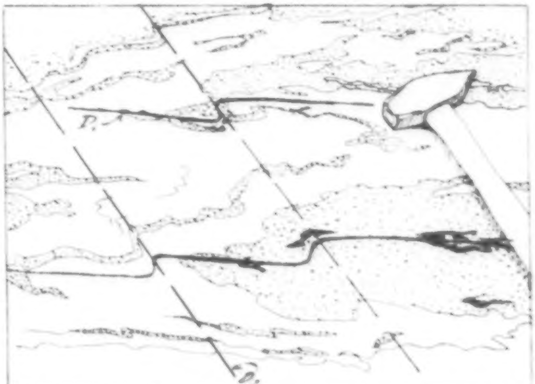

Figure 3 – Simplified sketch of refolded folds in mafic metavolcanics. Stippled areas represent amphibolite layers, solid areas represent hornblendite layers, unpatterned areas represent quartz-plagioclase layers. Bold solid lines represent D_1 fold axial traces and broken lines represent D_2 fold axial traces. Hammer for scale.

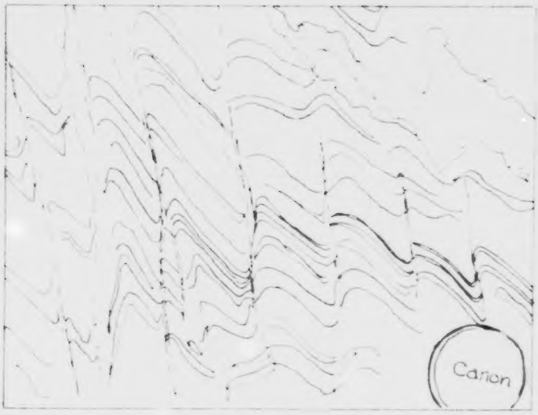

Figure 4 – Simplified sketch of secondary cleavage in well-layered psammitic gneiss, north-central D2. Stippled area represents slightly discordant coarse-grained quartz vein. Layering defined by relative abundances of quartz and K-feldspar. Lens cap for scale.

1 cm to about 25 cm. Amplitudes of the associated asymmetric folds show a similar dimensional range. The orientation of the cleavage zones varies somewhat in outcrop, and they even intersect each other at low angles in some places. Individual zones are discontinuous and heterogeneous, even at very small scales.

The relative age of this cleavage-forming event is not well understood, other than the fact that it is younger than the foliation and older than or coeval with the migmatization.

f) Putative Fault or Shear Zone

Layering in the lower structural levels of the Black Birch Antiform is not parallel to layering in the psammitic gneisses at higher structural levels. In fact, the layering in the psammitic gneisses does not relate to the antiformal structure, but rather consistently strikes north to northeast and dips easterly to southeasterly. This structural incongruency cannot be explained solely by an offset of the latest fold axial trace at the crossing of an earlier axial trace because of the absence of the northwest-dipping layering to the west. A fault or shear zone may have either reoriented the layering or simply juxtaposed orientations from different parts of the fold. If real, this structure would be expected to strike approximately northeast. Its presence may account for the anomalous dips in quartzite, the generally more aluminous and migmatitic nature of the rocks to the west relative to those to the east, and for such topographic features as asymmetric ridges. Presumably, the throw on such a structure need not be very great, since it does not apparently juxtapose units from greatly different parts of the structural sequence. The proposed structure must be considered highly conjectural, since field evidence for faulting or shearing is lacking.

4. Descriptions of Units

a) Tonalitic Gneisses

The tonalitic gneisses are typically low or lacking in K-feldspar, fine to medium grained, granoblastic and moderately to very well layered. The most common assemblage is plagioclase + quartz + biotite, but both K-feldspar- and hornblende-bearing bands exist. Neither magnetite nor orthopyroxene has been detected in this unit. Compositional layering is locally irregular and nebulous, but overall is well defined by the relative abundance of mafic minerals. In rare cases, a mineral foliation is defined by the parallel alignment of biotite grains within one layer to each other and to compositional layering.

Larger scale layering (tens of metres) is defined, in part, by relatively thin and laterally discontinuous zones of mafic enclaves. In highly strained rocks on the limbs of major folds, these zones occur as concordant layers carrying aligned elongate blocks of biotite schist or amphibolite. In these areas, foliations in the mafic enclaves are parallel to the local orientation of the regional tectonic foliation. Zones found near the hinges of major structures are still regionally concordant, but the blocks tend to be rounded or angular, and internally massive. The shapes of these blocks do not suggest that they are the fractured remains of a once-continuous layer.

Other mafic zones in tonalitic gneisses are clearly representative of disrupted planar features. The most common of these are 2 to 10 cm thick boudinaged granoblastic amphibolites (accompanying map). One sample of tonalitic gneiss was collected for zircon geochronologic analysis.

b) Augen Gneiss

This unit is brick-red, foliated, moderately well layered, coarse grained and porphyroclastic, and probably represents a deformed porphyritic granite. Layering is defined by relative grain size and abundance of augen; thin (1 to 4 cm wide), fine- to medium-grained equigranular layers separate thicker (metre-wide) layers of coarse-grained K-feldspar and plagioclase augen-rich rock. Plagioclase augen are less abundant and generally smaller than the K-feldspar augen, which are typically 1 to 2 cm long. Metre-wide alkali-feldspar granite pegmatite dykes are locally abundant, commonly cut layering, and may represent locally derived anatectic melts from the augen gneiss itself. Pegmatite dykes with such abundant K-feldspar are rarely found outside the augen gneiss. The borders of some of these dykes are coarser grained than the cores. Much of the layering may be related to intrusion of leucogranite (discussed below). One sample of augen gneiss was collected for zircon geochronologic analysis.

c) Biotite Leucogranite

Biotite leucogranite is pale pinkish-grey, with weathering colours ranging from orange to brown. The rock is fine- to medium-grained, equigranular, and locally exhibits an incipient foliation defined by parallel alignment of biotite grains. This foliation is broadly parallel to the regional tectonic foliation in the county rock. However, the leucogranite bodies (of probable sheet-like form) are generally slightly discordant to country-rock foliation, as evidenced by the truncation at low angles of those foliations by the leucogranite. Apophyses of leucogranite in tonalitic gneiss, augen gneiss and psammitic gneiss are also commonly slightly discordant. At one locality, a 50 cm thick dyke of leucogranite is apparently intruded along the contact between the augen gneiss and the tonalitic gneisses. At this outcrop, considerable apparent discordance (15° to 20°) of the dyke to layering in the augen gneiss can be observed, although not in the tonalitic gneiss. Apophyses of leucogranite in augen gneiss are ptygmatically folded. Some of the centimetre-wide, fine-grained concordant granitic veins in the augen gneiss can be traced into metre-wide and slightly discordant dykes of leucogranite. Two samples of biotite leucogranite were collected for zircon geochronologic analysis.

d) Psammitic and Psammopelitic Gneisses

Psammitic to psammopelitic gneisses are a heterogeneous group and include quartzofeldspathic gneisses, biotite gneisses and schists, quartzites, nearly massive meta-arkoses and very minor iron formation. These gneisses appear at various structural levels within the sequence and vary little from one level to the next.

Layered quartzofeldspathic gneisses, the most abundant variety, are most commonly fine grained and pink, grey, or white in outcrop. Some quartzites have both brick-red and yellow layers. The biotite gneisses are dark grey. Features observed more commonly in psammitic gneisses than in other units include 1) large and abundant cordierite crystals up to 20 cm long and abundant cordierite grains (commonly cored with sillimanite) in pods of anatectic melt, 2) kink-folds and secondary cleavages, 3) tourmaline pegmatites, and 4) faserkiesel. Muscovite appears only in the quartzofeldspathic gneisses or derived anatectic melts and, although locally abundant, is probably a retrogressive development because individual muscovite grains lie throughout at high angles to foliation in compositional banding.

One sample of probable iron formation and one sample of quartzofeldspathic gneiss were collected for possible geochronologic analysis of detrital zircon.

e) Metabasalt

Metabasalt forms a relatively thin unit a few metres thick. Exposures have been found only at and near the hinge of the Black Birch Antiform. The unit is distinct from other mafic units in its fine-grained texture, finely laminated (millimetre-scale) mineral layering, and complete lack of larger scale layering. Outcrops at the hinge of the Black Birch Antiform are composed entirely of black and compositionally homogeneous amphibolite. A few hundreds of metres away from the hinge, and probably at a slightly different structural level, both diopside and quartz are present in low abundance as millimetre-scale discontinuous lenses. Possible relict pillow structures occur at this locale. These structures are formed by discontinuous, centimetre-wide arcuate plagioclase + quartz ± diopside layers. In two dimensions, these layers enclose low-aspect ratio elliptical areas which cannot be related to local foliation or folding of foliation. Such layers are typically isolated from each other and rare overall.

f) Mafic Metatuffs and Metavolcanic Rocks

This unit is characterized by dark grey amphibolite, consisting primarily of fine-grained equigranular granoblastic hornblende, plagioclase and diopside. This amphibolite is generally finely laminated with alternating plagioclase-rich and hornblende-rich layers; hornblendite layers 4 to 6 cm wide are less abundant. Hornblendite-bounded quartz layers and lenses are dispersed throughout this unit, but are markedly less abundant overall than in the second mafic metavolcanic sequence (unit 7, Table 1). Some of the quartz layers exhibit pinch-and-swell structure. Plagioclase, diopside, hornblende and orthopyroxene are commonly included in the quartz lenses and layers.

Three mineralogically distinct subunits were observed in this unit:

Garnetiferous Amphibolite: Layers of 1 to 2 cm thick garnetiferous amphibolite are quite common. The garnetiferous amphibolite is associated with rusty-weathering sulphide zones, in which small garnet grains are abundant.

Porphyritic Amphibolite: Unfoliated porphyritic amphibolite consists of stubby hornblende porphyroblasts (typically less than 1 cm in diameter) in a granoblastic hornblende + plagioclase matrix. These layers are typically 1 to 4 m thick, and display rare relicts of pillow structure in the form of poorly defined arcuate diopside + plagioclase bands. The bulk of the unit may have derived from tuffaceous rocks.

Peraluminous Dykes: This subunit consists of coarse-grained and possibly anatectic peraluminous layers composed of K-feldspar + quartz + sillimanite + cordierite + garnet + biotite. Some layers of this approximate composition are concordant, whereas others are discordant and appear to have intruded along shear zones of small offset. Orthopyroxene was found in the amphibolite adjacent to contacts of some of these dykes, suggesting that intrusion of the dykes caused dehydration of the country rocks.

Four samples from this unit were collected for geochronologic analysis: one sample of concordant and one of discordant peraluminous rock, one of porphyritic amphibolite and one of the finely laminated amphibolite.

g) Pelitic Gneiss

This unit is well layered and foliated. The most abundant rock type is yellow-grey to white, coarse- to very coarse-grained gneiss composed of plagioclase + garnet + biotite + quartz + sillimanite + cordierite + K-feldspar. Subordinate rock types include black, fine-grained, garnet-bearing biotite schist, and greenish- or bluish-grey, very fine grained cordierite gneiss. Thin, discontinuous rusty-weathering zones are common and typically include pyrite and graphite. The pelitic gneisses are generally much coarser-grained and, in general, exhibit a lower abundance of anatectic melt than the psammitic gneisses in the same area, although very minor K-feldspar-rich pods can be found. Given the higher melting temperature of aluminous bulk compositions, this relationship supports the earlier suggestion of very local derivation of much of the melt observed. One rusty-weathering sulphide-bearing zone was sampled for sulphide lead isotopic analysis.

h) Mafic to Intermediate Metavolcanic Rocks

The mafic to intermediate volcanics are composed primarily of mineralogically variable amphibolites with very subordinate felsic material (typically quartz + plagioclase), calc-silicates and hornblendites. The feature which distinguishes this unit from other mafic units in the area is the high abundance of small, typically 1 to 15 mm wide, isoclinally folded quartz lenses and stringers ("fishhooks"). Amphibolites are typically dark greenish-grey, granoblastic and compositionally laminated at the millimetre scale. Diopsidic amphibolites are not layered, but have a foliation defined by millimetre-thick diopside lenses, most commonly mantled by equally thin rims of plagioclase, in a hornblende + plagioclase matrix. Hornblendite occurs as thin discontinuous layers and as discrete irregular clots within diopside and hornblende amphibolites. Calc-silicate layers in these amphibolites are typically composed of diopside + plagioclase. Garnet is a rarer accessory and orthopyroxene is rarer still. No vestiges of any primary volcanic structures, such as pillows, were observed.

Discontinuous interlayers of fine-grained, biotite-poor, nearly massive meta-arkose are more common within this unit than elsewhere and underscore the interpreted supracrustal origin of the unit. These layers range from less than one to several metres thick, and are characterized by centimetre-wide, irregular, coarse-grained quartz-plagioclase veins.

i) Quartzofeldspathic Gneiss (Possibly Felsic Metavolcanic Rock)

These rocks consist primarily of layered gneisses which contain variable quantities of quartz, plagioclase, K-feldspar and biotite. Felsic metavolcanic rocks are superficially similar to the tonalitic gneisses; however, the generally higher percentage of K-feldspar and lack of hornblende in the former serve to distinguish the two units. A volcanic protolith for this unit is suggested on the basis of its spatial association with the metasupracrustal sequence (a juxtaposition which is possibly entirely structural), and on the abundant, spaced (metres to tens of metres apart), subplanar zones of mafic enclaves. These discontinuous zones are parallel to the regional tectonic foliation and, as in the tonalitic gneisses, are thought to represent disrupted preexisting planar features such as sills, or intercalated flows in a volcanic or sedimentary pile. In the felsic metavolcanic rocks, these zones are not thought to represent dykes, as they are rare or absent in the remainder of the supracrustal sequence.

Layering, defined by relative abundance of biotite in the felsic metavolcanic rocks, varies from nearly nonexistent to well developed. Where layering is nearly nonexistent, the rock strongly resembles a somewhat deformed, equigranular granite; however, such rocks can be traced without break into rocks with well-developed layering. The felsic metavolcanic rocks are exposed entirely within the core of an isoclinal synform, so much of this variation is probably related to inhomogeneous deformation. Additionally, K-feldspar-bearing parts of the unit have compositions which resemble minimum melt compositions and may therefore represent stages in the process of rehomogenization by melting. Two samples of this unit were collected for zircon geochronologic analysis.

j) Pegmatite Dykes

Two examples of two types of felsic dyke were encountered: 1) aluminous biotite granite pegmatite and 2) granitic (peraluminous) pegmatite. The aluminous dykes contain garnet, biotite, relatively common tourmaline, sillimanite and cordierite; magnetite is locally both very abundant and coarse grained. The dykes are 10 to 20 m wide and can be traced for several tens of metres along strike. All four dykes are subconcordant with foliation in the country rock, and two of them carry large blocks of local country rock which are also subconcordant. Deformed fractured grains and incipient mineral foliation occur in all dykes, which are, in general, only weakly deformed.

As with neosomes of the migmatites, the mineral composition of these pegmatites appears to be related to the adjacent country rock; the aluminous pegmatites are associated with psammopelitic gneiss, whereas the granitic pegmatites are associated with quartzofeldspathic gneiss and/or amphibolite. This observation, coupled with the discontinous nature of the dykes, suggests that these pegmatites were possibly also locally derived by partial melting, but during times of waning deformation, when melt fractions were able to coalesce into slightly larger discordant bodies. Two pegmatite samples were collected for zircon geochronological analysis.

5. Metamorphism

The peak metamorphic conditions indicated by mineral assemblages in these rocks are in the upper amphibolite/granulite facies transition, as evidenced by the abundance of migmatites, by the presence of prismatic sillimanite in probable textural equilibrium with K-feldspar, and by the restricted occurrence of muscovite. Relatively low pressures (probably less than 5 kilobars) are suggested but not required by the absence of kyanite and the abundance of cordierite. High temperatures must have been reached before or at the time the F_1 folds were formed, because neosomes of migmatitic units are commonly isoclinally folded. Individual bent sillimanite grains were also observed in probable F_1 folds, but it is not clear about which orientation they were folded. That high temperatures may have persisted past the time of deformation is suggested by the granoblastic nature of much of the rock and by the observation of garnet and other minerals growing across compositional layering.

6. Projected Studies

It is hoped that geochronologic study will:

1) identify the oldest rocks in the area;
2) demonstrate whether protoliths of the tonalitic and augen gneisses are significantly older than protoliths of the metasupracrustal sequence;
3) constrain the duration of the sedimentary cycle that produced the supracrustal sequence;
4) demonstrate whether or not the protoliths of the supracrustal rocks are known units in the Mudjatik Domain; and
5) determine the age (or ages) and duration of metamorphic and deformational events.

Whole-rock geochemical study of rocks with probable igneous precursors should serve to constrain possible tectonic settings at the time of melting, as well as potential pressure-temperature conditions at the time of emplacement. Additionally, it may be possible to identify the sources of the neosomes of the migmatites and of the pegmatite dykes. Mineral chemical study of metamorphic assemblages is proposed in order to determine the sense and position in P-T space of the pressure-temperature-time path of the metamorphic event(s). The pressure-temperature-time path should yield a great deal of information about the sequence of orogenic events.

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8. References

Lewry, J.F. and Sibbald, T.I.I. (1977): Variation in lithology and tectonometamorphic relationships in the Precambrian basement of northern Saskatchewan; Can. J. Earth Sci., v14, p1453-1467.

__________ (1980): Thermotectonic evolution of the Churchill Province in northern Saskatchewan; Tectonophysics, v68, p45-82.

Sibbald, T.I.I. (1973): 74-B-NW: Mudjatik (nw); *in* Summary Report of Geological Investigations Conducted in the Precambrian Area of Saskatchewan; Sask. Dep. Miner. Resour., p35-42.

Thomas, M.W. (1984): Compilation bedrock geology: Mudjatik area (NTS 74B); 1:250,000 scale prelim. map *with* Summary of Investigations 1984, Sask. Geol. Surv., Misc. Rep. 84-4.

Van Schmus, W.R., Bickford, M.E., Lewry, J.F. and Macdonald, R. (1987): U-Pb geochronology in the Trans-Hudson Orogen, northern Saskatchewan, Canada; Can. J. Earth Sci., v24, p407-424.

Project 8804

The Virgin River Shear Zone in the Careen Lake Area: Field Relationships and Kinematic Indicators[1]

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Carolan, J. and Collerson, K.D. (1988): The Virgin River Shear Zone in the Careen Lake area: Field relationships and kinematic indicators; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

This paper presents results of fieldwork in the Careen Lake area of northern Saskatchewan which commenced this summer (Figure 1). The area was selected for study because it exhibits a well-exposed section across the Virgin River Shear Zone. This approximately 4.5 km wide zone of mylonitic rocks separates dominantly granulite facies quartzofeldspathic gneisses of the Western Granulite Domain in the west from lower grade supracrustal rocks and felsic gneisses of the Virgin River Domain in the east. Previous reconnaissance mapping of the shear zone was carried out by Sibbald and Lewry (1973 and 1974), Wallis (1970) and Johnson (1968). The present study forms part of a second-phase mapping project at a scale of 1:20,000. This study area forms a segment of a regional transect crossing the Virgin River Shear Zone from the Cree Lake Zone (Orrell and Bickford, this volume) in the east to the Western Granulite Domain (Crocker and Collerson, this volume). The study is being undertaken to evaluate kinematic indicators in the Virgin River Shear Zone. Such information may be applied in determining whether this zone represents a crustal collisional suture, or an intracontinental transcurrent fault related to the Trans-Hudson Orogeny.

1. Regional Setting

The Virgin River Shear Zone (Lewry and Sibbald, 1977), the Black Lake Shear Zone (Gilboy, 1980) and the Tulemalu Fault Zone (Tella and Eade, 1986) are components of what has been collectively termed the Snowbird Tectonic Zone (Hoffman, 1988). This major zone, extending 3000 km from the Rocky Mountains in Southern Alberta to the Hudson Strait in the Northwest Territories, separates the Rae and Hearne Provinces (Hoffman, 1988). The zone has been interpreted as either a crustal suture or an intracontinental reactivation structure resulting from Hudsonian thermotectonism (Lewry and Sibbald, 1977).

In the Careen Lake area (Figure 1), the Virgin River Shear Zone separates high-grade Archean rocks of the Western Granulite Domain from lower amphibolite facies rocks of the Virgin River Domain. Gneissic relationships in the Western Granulite Domain reflect a complex lithostructural history (Crocker and Collerson, this volume). The gneisses appear to have been derived from a variety of protoliths, including granite, granodiorite, tonalite, gabbro and anorthosite. Although the gneisses experienced granulite facies metamorphism, they also show the effect of a lower amphibolite facies overprint, possibly related to Hudsonian thermotectonism (Lewry and Sibbald, 1980).

The Cree Lake Zone east of the Virgin River Shear Zone, comprising the Virgin River and Mudjatik Domains (Figure 1), is dominated by granitic felsic gneisses and interlayered supracrustal rocks. Metamorphic grades in the Mudjatik Domain range from upper amphibolite to granulite facies, whereas rocks in the Virgin River Domain are lower amphibolite facies.

Virgin River Shear Zone mylonites at Careen Lake appear to have been derived from rocks of both the Western Granulite Domain and the Virgin River Domain. South of Careen Lake, the Virgin River Shear Zone is cut by the Junction Granite, which gives a U-Pb zircon crystallization age of 1820 ± 10 Ma (Bickford, 1986). Lewry and Sibbald (1977) have shown that the Junction Granite experienced three periods of ductile/brittle deformation associated with movement along the fault zone.

2. Lithology

a) Virgin River Schist Group (VRSG)

The Virgin River Schist Group (Johnson, 1968; Wallis, 1970) consists of psammopelitic metasediments and possible metatuffs bounding a thin continuous unit of metabasalt. These fine- to medium-grained metasediments contain biotite, quartz, feldspar, garnet, muscovite, staurolite and andalusite. Locally, a well-developed phyllitic texture is developed. The fine- to medium-grained metabasalt contains actinolite, hornblende, Fe-Ti oxides and feldspars. In outcrop-scale areas of low finite strain, relict deformed pillow structures are recognized. The VRSG is cut by tourmaline-bearing pegmatites, but lacks the mafic dykes common in the bordering rock units (see below). The contact between the VRSG and the main mylonite zone is gradational.

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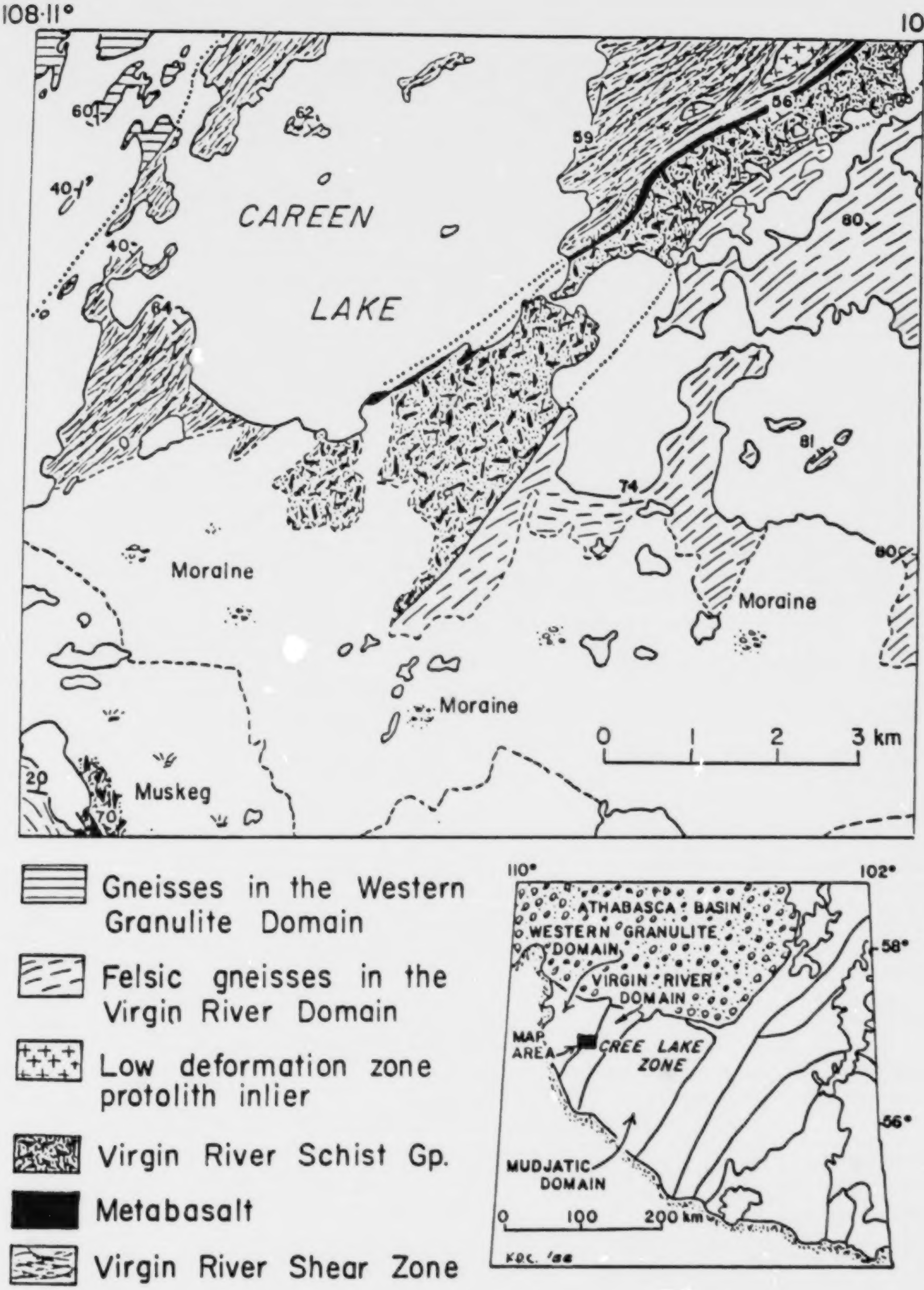
108·11°
108·1°
57°
CAREEN
LAKE
60
62
40
40
64
59
56
80
81
74
80
20
70
Moraine
Moraine
Moraine
Muskeg
0 1 2 3 km
Gneisses in the Western Granulite Domain
Felsic gneisses in the Virgin River Domain
Low deformation zone protolith inlier
Virgin River Schist Gp.
Metabasalt
Virgin River Shear Zone
110°
102°
58°
56°
ATHABASCA BASIN
WESTERN GRANULITE DOMAIN
VIRGIN RIVER DOMAIN
MAP AREA
CREE LAKE ZONE
MUDJATIC DOMAIN
0 100 200 km
KDC. '88

Figure 1 - Map showing relationships between major rock types in the Virgin River Shear Zone, Careen Lake area.

b) Felsic Gneisses of the Mudjatik Domain

The Mudjatik Domain comprises quartzofeldspathic gneisses derived from granitic, granodioritic and tonalitic protoliths (Orrell and Bickford, this volume). Gneisses derived from these protoliths are also cut by amphibolite dykes. The gneisses are characterized by assemblages of quartz, plagioclase, potassium feldspar, hornblende, biotite and Fe-Ti oxides. The contact between this terrain and the supracrustal rocks of the VRSG is not exposed in the area mapped.

c) Western Granulite Domain

Rocks of the Western Granulite Domain consist of quartzofeldspathic gneiss derived from granitic, granodioritic, tonalitic, gabbroic and anorthositic protoliths (Crocker and Collerson, this volume). Mineral assemblages indicative of granulite facies conditions are widely preserved in these gneisses. The contact between the Western Granulite Domain and the Virgin River Shear Zone is gradational over a distance of 0.5 km and is reflected in the progressive change from protomylonitic to mylonitic rocktypes.

d) Pegmatites

Crosscutting relationships indicate that four periods of pegmatite intrusion affected the area. Bodies of pegmatite occur either obliquely to planar fabrics or along axial planar cleavage traces.

3. Field Characteristics of the Virgin River Shear Zone

The Virgin River Shear Zone is defined by an approximately 4.5 km wide northeast-trending belt of mylonitic rock derived from plutonic, volcanic and sedimentary protoliths. Plutonic components include granodiorites, diorites, tonalites, granites and diabase dykes. The volcanic unit consists of a relatively thin sequence of pillow basalts. Metasediments range from pelitic to psammitic but are generally psammopelitic.

The mylonite zone contains two zones of low finite strain characterized by a body of tonalitic-granodioritic gneiss which is cut by granitic augen gneiss and amphibolitic metadiabase dykes. These important zones are approximately 2.5 by 0.5 km and 0.5 by 0.25 km in size. The contact between the gneissic enclaves and the surrounding mylonite is complex and gradational. Along the eastern boundary of the larger low deformation zone, the contact is defined by a series of mylonitized and flattened augen gneisses that grade into protomylonite. The boundary of the smaller low deformation zone is characterized by a textural path grading from protomylonite to ultramylonite.

Metasedimetary mylonites occur intermittently throughout the Virgin River Shear Zone. These units are compositionally similar to rocks in the VRSG to the east, suggesting that part of the VRSG has been incorporated into the mylonite zone. Contacts between these units and the plutonic and volcanic components of the shear zone are sharp and planar. These contact relationships are probably the result of transposition of units during ductile deformation.

4. Structural Geology

a) Folding

At least four episodes of folding are recognized in the Virgin River Shear Zone and the Virgin River Domain (Figure 1). Rare F_1 folds occur as small rootless isoclinal folds. These intrafolial folds are refolded by a northeast-plunging folding event (F_2). These F_2 folds are tight to isoclinal, with plunges ranging from steep to shallow. F_2 folds occur on both mesoscopic and macroscopic scales. The F_2 folds are refolded by northwest-trending F_3 folds. Recognition of this D_3 event could only be made on a mesoscopic scale. Postmylonitic deformation (D_4) includes localized reverse kink banding and box folding of the mylonitic fabric. Due to poor exposure in the Western Granulite Domain, documentation of folding relationships was not possible.

b) Faulting

Faulting in the area reflects the effect of ductile and brittle deformation. The main mylonite zone and small-scale oblique shear bands show dextral displacement due largely to the effect of ductile deformation. Later brittle faulting is both oblique and parallel to the main mylonitic fabric. Along the mylonitic fabric plane, pegmatite and granitic dykes show dextral offset. Two conjugate brittle fault sets are also present. One set, oriented at approximately 040° to 080° shows normal dextral offset and is commonly associated with the

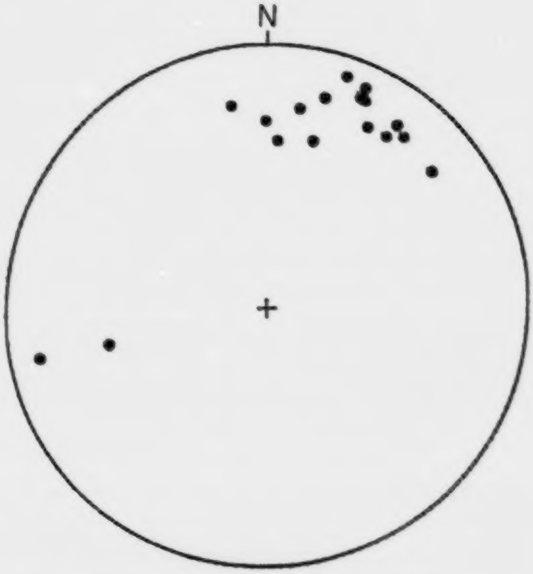

Figure 2 – Plunges of mineral lineation defined by the alignment of hornblende, biotite and feldspar. Mean plunge is approximately 22°.

development of fault breccia and drag folds. The other fault set, oriented at approximately 340° to 360°, exhibits normal sinistral offset. These conjugate faults are interpreted to have resulted from brittle failure of more competent layers during extension along the main shear zone.

The penetrative foliation of the mylonite zone (S_2) is believed to have formed by reorientation of an earlier foliation (S_1). The earlier foliation is commonly preserved as an internal fabric within asymmetric pinch-and-swell structures. The dominant foliation (S_2) dips to the northwest at between 35° and 80°, with most dips being between 55° and 70°. Mineral lineations defined by aligned hornblende, biotite and feldspar grains plunge to the northeast at 11° to 40°, averaging approximately 22° (Figure 2). The plunge of the lineation suggests that the major component of motion is strike slip with a minor dip slip component. The orientation of the fault plane, together with the juxtaposition of a high-grade terrain and a low-grade terrain, suggests that a minor component of reverse faulting is also present (see Figure 3).

c) Kinematic Indicators

Kinematic indicators of fault movement observed in the field include rolling structures, asymmetric pinch-and-swell structures and offset dykes and veins (Figure 4). Although most rolling structures observed are ambiguous, those with clear asymmetry are dominately of the Z-type of Van Den Dreissche and Brun (1987). Rolling structures observed in the area are typically feldspar porphyroblasts with asymmetric tails derived from the porphyroblast. These appear to have formed as a result of rotation of a rigid object in a ductile matrix during shearing (Van Den Dreissche and Brun, 1987). Rolling structures which display Z-type geometry, similar to those observed in the area, indicate a dextral sense of shearing.

Asymmetric pinch-and-swell structures recognized in the area are of the Type 2 class of Hamner (1986), and are developed in layers of amphibolite surrounded by a less competent quartzofeldspathic matrix. Shear along the plane of extension commonly produces an antithetic rotation of the swell section of the structure. Observations of such rotated structures in this area indicate that the sense of shear was dextral.

Offset granitic and pegmatitic dykes and veins were also observed in the area. These late dykes cut the penetrative mylonitic foliation at a high angle and show the effect of dextral offset in the plane of the mylonitic fabric. This observation indicates that offset was dextral and there were multiple periods of fault movement.

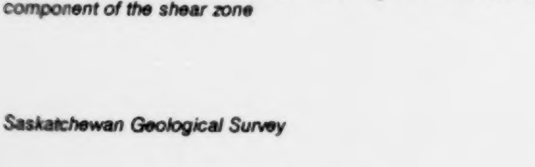

Figure 3 - Schematic cross-section showing the minor reverse component of the shear zone

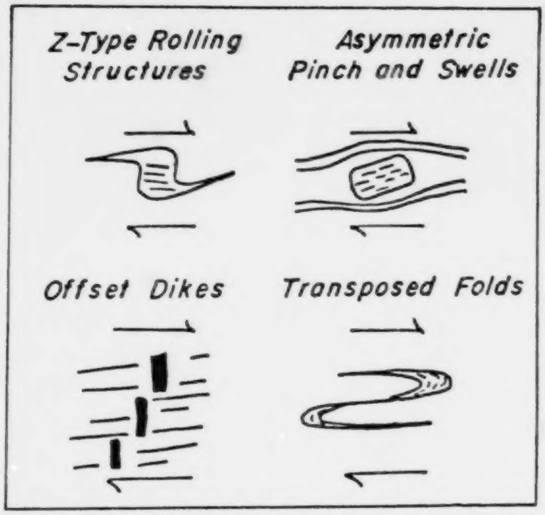

Figure 4 - Kinematic indicators used to establish fault movement in the Virgin River Shear Zone

5. Metamorphism

Mineral assemblages of rock units east of the mylonite zone indicate lower amphibolite facies metamorphism. Assemblages include hornblende, biotite, quartz, plagioclase, K-feldspar, andalusite, garnet and staurolite. Secondary minerals include epidote and chlorite. Staurolite inclusions in garnets and synkinematic and postkinematic andalusite suggest an extensive period of crystal growth.

Mineral assemblages of rock units west of the mylonite zone indicate granulite facies metamorphism with subsequent lower amphibolite facies retrogression. Relic orthopyroxene and blue quartz define the older mineral assemblage. The lower amphibolite mineral assemblage includes hornblende, biotite, quartz, feldspar, magnetite and ilmenite. Secondary minerals include goethite, amorphous sphene, chlorite and epidote.

6. Samples Collected for Further Study

Samples of the metasediments from the VRSG, orthogneisses from the major low shear domain, and felsic gneisses from the Mudjatik Domain have been collected for U-Pb geochronology. Such information will be used to determine the relationship of the metasediments to the surrounding quartzofeldspathic gneisses. Mylonitized pillow basalt and metadiabase dykes have been sampled for Sm-Nd analysis. Offset granitic and pegmatitic dykes were sampled for Rb-Sr analysis. This information will be necessary in determining timing of brittle failure along the fault zone.

7. Summary

1) The area exhibits a well-exposed section across the Virgin River Shear Zone. This approximately 4.5 km wide zone of mylonitic rocks separates the high-grade Archean rocks of the Western Granulite Domain from lower amphibolite facies rocks of the Virgin River Domain.

2) The Virgin River Shear Zone incorporates low-deformation zones in which primary intrusive features of Cree Lake Zone gneisses are preserved.

3) Relict pillow structures preserved in outcrop-scale low-deformation areas suggest the possibility that a early rift sequence may exist in the area.

4) At least four episodes of folding affected the Virgin River Shear Zone and the Virgin River Domain.

5) Stretching lineations observed in the field plunge at 11° to 40°, averaging approximately 22°. This plunge suggests that the major component of motion was strike-slip.

6) Kinematic indicators, including rolling structures, asymmetric pinch-and-swell structures and offset veins and dykes, indicate that strike-slip motion was dextral.

8. Acknowledgements

We are grateful to Saskatchewan Energy and Mines for financial support of field work. R. Macdonald and C.T. Harper coordinated, expedited and provided logistics for field work. J.F. Lewry and M.E. Bickford provided stimulating discussions on interpretations of field relationships. Able field assistance was provided by Greg Grimsich. This research was also supported by a National Science Foundation Grant (EAR 87-20442) to Collerson and Bickford.

9. References

Bickford, M.E., Van Schmus, W.R., Macdonald, R. , Lewry, J.F. and Pearson, J.G. (1986): U-Pb zircon geochronology project for the Trans-Hudson Orogen: current sampling and recent results; *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep. 86-4, p101-107.

Hamner, S. (1986): Asymmetric pull-aparts and foliation fish as kinematic indicators; J. Struct. Geol., v8, no2, p111-122.

Hoffman, P.F. (1988): United plates of America, the birth of a craton: early Proterozoic assembly and growth of Laurentia; Annu. Rev. Earth Planet. Sci., v16, p543-603.

Johnson, R.L. (1968): The geology of the Nyberg Lakes area (west half), Saskatchewan; Sask. Dep. Miner., Rep. 118, 15p.

Lewry, J.F. (1974): Structural relationships in the La Loche (north) map sheet and adjacent areas; *in* Summary Report of Field Investigations by the Saskatchewan Geological Survey, 1974; Sask. Dep. Miner. Resour., p46-55.

Lewry, J.F. and Sibbald, T.I.I. (1977): Variation in lithology and tectonomorphic relationships in the Precambrian basement of northern Saskatchewan; Can. J. Earth. Sci., v14, p1453-1467.

Sibbald, T.I.I. (1973): 74-B-NW: Mudjatik (nw); *in* Summary Report of Geological Investigations Conducted in the Precambrian Area of Saskatchewan, 1973; Sask. Dep. Miner. Resour., p35-42.

Tella, S. and Eade, K.E. (1986): Occurrence and possible tectonic significance of granulite fragments in the Tulemalu fault zone, Distict of Keewatin, N.W.T., Canada; Can. J. Earth. Sci., v23, p1950-1962.

Van Den Dreissche, J. and Brun, J.-P. (1987): Rolling structures at large shear strain; J. Struct. Geol., v9, no5/6, p691- 704.

Wallis, R.H. (1970): The geology of the Dufferin Lake area (west half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 132, 59p.

Archean and Early Proterozoic Field Relationships in the Careen Lake Area of the Western Granulite Domain[1]

C.H. Crocker[2] and K.D. Collerson[2]

Crocker, C.H. and Collerson, K.D. (1988): Archean and Early Proterozoic field relationships in the Careen Lake area of the western Granulite Domain; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

As part of a collaborative project between the Saskatchewan Department of Energy and Mines, the University of California at Santa Cruz and the University of Kansas, a new phase of geological mapping at a scale of 1:20,000 was initiated during the summer of 1988 in the Western Granulite and Cree Lake Domains. The objective of this study is to resolve crustal evolutionary relationships in the Western Granulite Domain and to develop an integrated tectonic history for the Virgin River Shear Zone in the context of crustal assembly of the North American Craton. This report on the geology of the Careen Lake area was undertaken to investigate the crustal evolutionary history of Archean gneisses in the Western Granulite Domain and to resolve the relationship between the Clearwater Anorthosite Intrusion and these gneisses.

The report contains details of lithological relationships, rock descriptions and a provisional lithostructural chronology. Approximately 40 percent of the area mapped during the summer was burned over recently. Much of the lithostructural interpretation is based on observations made in these areas.

1. Regional Geology

Located in northwestern Saskatchewan, the Western Granulite Domain of the Canadian Shield has been interpreted by Lewry and Sibbald (1980) as 'deep' Archean continental crust only mildly affected by Hudsonian thermotectonism. The Western Granulite Domain forms part of the Rae Craton (Hoffman, 1988). It is separated from the Hearne Craton in the east by the Virgin River, Black Lake and Tulemalu Shear Zones, collectively termed the Snowbird Line. Timing of movement along the Virgin River portion of the Snowbird Line is constrained by the Junction Granite which yields a U-Pb age of 1820 Ma and contains xenoliths of blastomylonite from the Virgin River Shear Zone (Bickford et al., 1986). The Snowbird Line has been interpreted as an intracontinental reactivation structure related to the Trans-Hudson Orogen (Lewry and Collerson, in press; Hoffman 1988). Gneisses in the Careen Lake area west of the Virgin River Shear Zone (Figure 1) are derived from a variety of plutonic protoliths, including granite, granodiorite, diorite, tonalite, anorthosite, gabbro-anorthosite and pyroxenite. Subordinate rock types include metapelites, metapsammites and quartzites. Intrusive contacts between protoliths of the orthogneisses have been largely rotated into parallelism to yield a layered gneissic sequence. Metamorphic mineral parageneses are interpreted by Lewry and Sibbald (1980) as indicating prograde granulite facies overprinted by retrograde amphibolite facies.

2. Previous Work

The upper Clearwater River area east of Lloyd Lake was mapped by Sproule (1941) at a scale of 1:253,440. A more detailed investigation of the upper Clearwater portion of NTS area 74F (Lloyd Lake) was undertaken at a scale of 1:100,000 by Scott (1985). Sibbald (1973) and Lewry (1974) mapped approximately 7000 km in the La Loche and Mudjatik map areas and developed a regional synthesis of the terrain (Lewry and Sibbald, 1977). A reconnaissance platinum group element evaluation of mafic and ultramafic rocks from the Fournier-Careen-Camel Lakes area, including the Clearwater Anorthosite Intrusion, was undertaken by Hulbert (1987).

3. Lithostructural Chronology

The western Careen Lake area is dominated by a complex sequence of mixed high-grade quartzofeldspathic gneisses (Figure 1; Table 1). Within this area, extensive burn has exposed many small-scale lithological features that have allowed age relationships to be deduced. The nature and relation of the protoliths are largely preserved in areas of low finite strain.

Many of the mixed gneisses contain angular agmatitic trains of anorthosite, gabbro and pyroxenite engulfed in a leucosome of leucogranite and diorite. These relationships are interpreted as indicating that the oldest rocks in the region are part of a layered basic complex that has been intruded by multiple phases of granite, tonalite and diorite.

Finely layered mixed quartzofeldspathic gneisses were produced by transposition of agmatitic units and sheet-like igneous bodies during deformation.

The gneisses are cut by semiconcordant to concordant sheets of granite, diorite and possibly a second phase of anorthosite. The sheets range in thickness from 10 to

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(1) Field Support provided under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89, in joint venture with the University of California, Santa Cruz

(2) Earth Sciences Board University of California, Santa Cruz, California, 95064

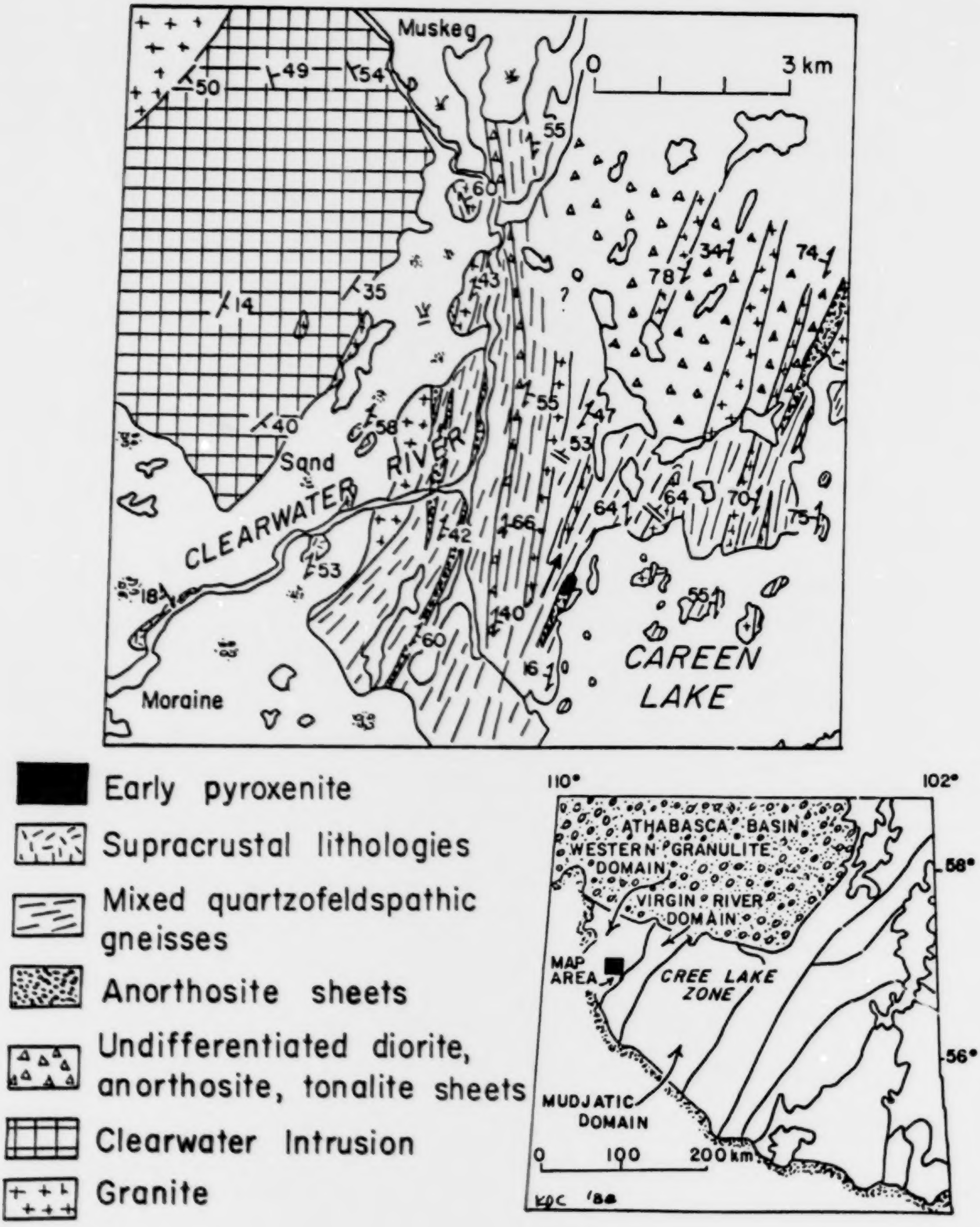
Muskeg
0
3 km
50
49
54
55
60
35
14
43
78
34
74
?
55
47
53
40
58
Sand
RIVER
CLEARWATER
64
64
70
75
42
66
53
18
40
55
60
16
CAREEN
LAKE
Moraine
Early pyroxenite
Supracrustal lithologies
Mixed quartzofeldspathic gneisses
Anorthosite sheets
Undifferentiated diorite, anorthosite, tonalite sheets
Clearwater Intrusion
Granite
110°
102°
58°
56°
ATHABASCA BASIN
WESTERN GRANULITE DOMAIN
VIRGIN RIVER DOMAIN
MAP AREA
CREE LAKE ZONE
MUDJATIC DOMAIN
0
100
200 km
KDC '88

Figure 1 – Geological map showing principal lithological relations in the Careen Lake area of the Western Granulite Domain.

100 cm and commonly display layer-parallel foliation. They were emplaced late in the structural evolution of the terrain after the development of S-fabrics in the layered quartzofeldspathic gneisses. The mixed gneisses show evidence of incipient anatectic melting producing diffuse structureless patches, as well as net veins and pegmatite dykes which commonly obliterate earlier foliation. The mixed quartzofeldspathic gneisses are also intruded by sheets of massive posttectonic meladiorite.

Supracrustal rocks are common throughout the area. At one locality, a contact of quartzite and calc-silicate rock against fractured pyroxenite may represent a fossil regolith surface. These supracrustal rocks may also record sedimentation prior to the intrusion of the component granitoids of the mixed quartzofeldspathic gneisses. Intrusive relationships between granite and supracrustal rocks were not, however, observed at this locality. Elsewhere, supracrustal units occur as isolated outcrops or as discrete 50 to 100 cm wide layers within the layered quartzofeldspathic gneisses.

All rocks in the area are cut by pink granitic pegmatite dykes which were apparently emplaced in fractures that commonly offset the banding in the gneisses. These dykes are also faulted, producing small conjugate mylonitic shear zones. Chlorite-rich mylonites are commonly developed along the centres of some pegmatites, indicating movement and passage of fluids along these fractures following emplacement of the dykes.

The Clearwater Anorthosite Intrusion crops out in the western part of the map area. As contacts with compositionally layered mixed quartzofeldspathic gneisses are obscured by sand deposits and muskeg, it is difficult to determine the relative age of the Clearwater Anorthosite. At some localities within the intrusion, primary igneous layering is truncated and angular anorthosite blocks are engulfed in porphyritic units of melagabbro, indicating multiple intrusions of anorthosite. The anorthosite body is cut by tabular sheets of posttectonic granite.

4. Major Rock Units

Anorthosite, Leucogabbro and Pyroxenite Agmatite: Variably deformed blocks of anorthosite, leucogabbro and pyroxenite occur within the mixed quartzofeldspathic gneisses. At some localities these units are relatively continuous, forming up to 85 percent of individual outcrops, but more commonly they are a minor component of the gneisses.

Supracrustal Rocks: Included amongst the supracrustal rocks is an assemblage of metapsammites, metapelites and quartzites. The metasediments are commonly interlayered with metavolcanics.

Mixed Quartzofeldspathic Gneisses: These strongly flattened gneisses were derived from a variety of rocks by deformation of intrusive rocks, including granite, granodiorite, tonalite and diorite, which cut early agmatitic anorthosites and gabbros.

Table 1 – Simplified Table of Geological Events

YOUNGEST

9) Mylonitization (probably Proterozoic) and small-scale faulting related to the Virgin River Shear Zone

8) Intrusion of pegmatites

7) Intrusion of late granite and diorite

6) Possible emplacement of the Clearwater Anorthosite Intrusion

5) D_2 folding and localized anatectic reworking

4) Homogeneous deformation (D_1) of the agmatitic unit forming the mixed quartzofeldspathic gneisses and syntectonic (D_1) intrusion of granite, tonalite, diorite and more anorthosite

3) Intrusion of granitoids to produce units of agmatitic anorthosite and gabbro

2) Deposition of the Careen Lake Group (Scott, 1985) and other supracrustal material, including pelites, psammites, quartzites and metavolcanics (as inferred from their interpreted position overlying the regolith on the large pyroxenite body)

1) Fractionation of mafic magma to produce anorthosite, gabbro-anorthosite and pyroxenite which was emplaced in an unidentified crust

OLDEST – ARCHEAN(?)

Homogeneous Granites: Homogeneous granites occur as concordant sheets within the mixed quartzofeldspathic gneisses. These wider layers of granite, anorthosite to leucogabbro, and diorite probably represent later stage intrusions into the compositionally layered mixed quartzofeldspathic gneiss complex. Where volumes of individual rock types exceed 50 percent, they have been mapped as distinct units. Granite sheets within the Clearwater Anorthosite body may be of similar age.

Clearwater Anorthosite Intrusion: This large body of medium- to coarse-grained blue-grey anorthosite to gabbro-anorthosite exhibits well-defined cumulus layering on scales ranging from a half to many metres in thickness. Primary layering is locally cut by melagabbro and mafic diorite.

5. Field Characteristics of the Major Rock Units

a) Leucogabbro and Anorthosite Agmatite

The oldest anorthosites occur as 10 to 20 cm diameter angular blocks of coarse-grained grey plagioclase with up to 10 percent intercumulus orthopyroxene. Hornblende commonly replaces the orthopyroxene. The angular anorthosite blocks contain plagioclase crystals, ranging between 5 and 15 cm in length, that show evidence of recrystallization to fine-grained (5 and

10 mm diameter) equigranular aggregates. Granitoid rock which intrudes these anorthosites, producing agmatitic units, may be the oldest granite in the area. Anorthosite also occurs as flattened-foliated xenoliths up to 50 cm in size within the mixed gneisses.

b) Leucogabbro, Tonalite and Anorthosite Bands

North of Careen Lake, medium- to coarse-grained units of anorthosite and leucogabbro containing extremely dark plagioclase occur as subconcordant to concordant layers up to 2 m in width interlayered with granites and mixed quartzofeldspathic gneisses. Anorthosite layers in leucogabbro are commonly boudinaged and exhibit leucosomes of partial melt in pressure shadows between the boudins. These units are locally associated with quartz-bearing anorthosites and diorites that appear to grade into tonalitic rock. These tonalites are distinguished from components in the mixed quartzofeldspathic gneisses by the presence of darker plagioclase and clear quartz. These may reflect the effect of assimilation between gabbroic magma and crustal melts.

Sheets of leucogabbroic and anorthositic material north of Careen Lake appear mineralogically and texturally similar to the more mafic anorthosites and leucogabbros in the main mass of the Clearwater Intrusion. Hulbert (1987) has suggested that these sills were emplaced at the same time as the main Clearwater Anorthosite Intrusion.

c) Clearwater Anorthosite Intrusion

In areas mapped during the summer of 1988, the Clearwater Anorthosite Intrusion is dominated by blue-grey plagioclase with less than 10 percent orthopyroxene, clinopyroxene, hornblende and magnetite. Gabbronorite layers in the anorthosite range from 1 to 30 cm in width and grade into pure anorthosite over a few centimetres. This primary layering is commonly oblique to the regional layering in the gneisses.

It is difficult to establish stratigraphic relationships within the intrusion due to the extreme degree of minor faulting, as well as the effect of multiple intrusion within the anorthosite and late-stage dyking.

Intrusive relationships are displayed at two localities along the eastern margin of the anorthosite body. At one of these localities, angular blocks of coarse-grained light grey anorthosite, ranging in diameter from tens of centimetres to many metres, are included in a matrix of coarse-grained melagabbro. Individual anorthosite blocks are veined by this phenocrystic pyroxene-bearing unit and are commonly exploded into small angular fragments of anorthosite. At the other locality, primary layering is cut by veins of massive anorthosite. Further to the west the anorthosite is much more homogeneous, displaying primary layering that consistently strikes north-south and dips approximately 40° east.

Mafic diorite dykes, usually less than 1 m in width, intrude the anorthosite body and are in turn cut by much thinner pegmatitic granite dykes. However, these relationships are commonly obscured by minor faults.

d) Pyroxenite

The most significant exposure of the pyroxenite unit is a coarse-grained, 300 by 500 m ovoid body composed of orthopyroxenite and clinopyroxene-bearing orthopyroxenite with variable amounts of phlogopite. The unit displays a possible regolith surface defined by brown angular blocks of pyroxenite separated and penetrated by 2 to 5 cm wide pallid zones consisting of fine-grained plagioclase. Similar pyroxenite also occurs in the mixed quartzofeldspathic gneisses as deformed layers and angular to lenticular pods up to 1 m in diameter.

e) Supracrustal Rocks

Isolated outcrops of supracrustal rocks occur east of the Clearwater Anorthosite Intrusion and appear to be intruded by sheets of massive garnetiferous granite pegmatite, forming a supracrustal gneiss complex. Supracrustal rock types include quartzites, metapelites and metavolcanics. The metamorphic mineralogy of the fine-grained highly foliated metavolcanics includes biotite, orthopyroxene and plagioclase, and shows no signs of retrogression from granulite facies. The pegmatite sheets, which exhibit pinch-and-swell structure and have sharp irregular contacts with the metavolcanics, are made up of 1 to 10 cm diameter porphyroblasts of garnet, plagioclase and quartz with minor cordierite and graphite. The pelitic gneisses exhibit a strong foliation defined by biotite, and sillimanite that shows retrogression to fibrolite. Garnet porphyroblasts in the pelitic gneisses are commonly larger than 10 cm in diameter. Quartzite layers, which range from 5 to 20 cm in thickness, are rare in the supracrustal gneisses.

Garnetiferous quartz diorite to granite was observed at two localities in small layers ranging in width from 10 to 50 cm. These migmatitic layers are interpreted as partial melts of pelitic components within the supracrustal assemblage.

f) Mixed Quartzofeldspathic Gneisses

This composite unit is dominated by compositionally layered granodiorite (<60 percent) with subordinate amounts of granite (<20 percent), diorite (<15 percent) and agmatized anorthosite, leucogabbro and pyroxenite. All lithological components in the gneisses show variable development of composite layering (generally due to variation in modal proportions of hornblende, orthopyroxene, plagioclase, blue and white quartz, and potassium feldspar), as well as a strong layer-parallel foliation.

The gneisses exhibit variable degrees of anatectic melting, shown by net veining, homogenization of rock types and a loss of banding. With increasing anatexis, banding is diffuse and net veins of white feldspar, quartz, orthopyroxene, clinopyroxene and hornblende are developed. After extensive homogenization, the only evidence of banding and folding is diffuse foliation defined by mafic minerals and slightly folded net veins.

Following the development of these partial melts, the gneisses were intruded by dioritic and pegmatitic granite dykes. These diorite dykes are distinguished in the field from the diorite bands in the mixed quartzofeldspathic gneisses by a greater percentage of fine-grained hornblende and a darker feldspar. The granite pegmatites are pink to orange in color, virtually free of mafic minerals, seldom folded and never exceed 50 cm in width.

g) Granites

Concordant sheets of medium-grained granite, 1 to 25 m thick and locally much thicker, intrude the finely layered mixed quartzofeldspathic gneisses. Metamorphic minerals include blue quartz, white plagioclase, potassium feldspar, minor orthopyroxene and hornblende. Granite north of Careen Lake is interlayered with anorthosite and tonalite. Where granite constitutes as much as 50 percent of these outcrops, it has been mapped as a separate unit.

The granite occurring west of the Clearwater River commonly contains porphyroclastic augen of dark antiperthitic feldspar similar to augen found in finely banded and highly foliated layers of quartz monzonite-tonalite commonly interlayered with this granite. The granite layers have an average width of 30 cm and commonly display pinch-and-swell structure.

h) Structure

The general trend of the foliation and compositional banding in the gneisses from the Careen Lake area ranges from 350° to 020°. Banding in the gneisses generally ranges from 1 to 5 cm in width, although concordant sheets of granite, anorthosite and diorite commonly exceed 3 m in width. Intrafolial folds (F_1) and local rotated structures indicate rotational shear during flattening. Layering in the mixed quartzofeldspathic gneisses commonly displays extensive small-scale isoclinal folding (F_2). A large synform (F_3), which plunges at shallow angles to the north through the centre of the field area has an amplitude greater than the length of the field area.

There are three dominant foliations in the Careen Lake area. S_1 is defined by the alignment of ferromagnesian minerals and quartz lenticles parallel to compositional layering in the mixed quartzofeldspathic gneisses. S_2 fabrics are developed in the hinges of F_2 mesoscopic folds. Regionally developed fabrics oblique to S_1 are believed to have formed during F_2 deformation and are therefore considered to be an S_2 foliation surface. Foliated sheets of finely layered, porphyroclastic tonalite are interlayered with the slightly foliated homogeneous granite. These sheets cut the mixed quartzofeldspathic gneisses and display layer-parallel S_3 foliation parallel to S_1.

Small-scale dextral and sinistral conjugate faults, typically with less than 10 m offset, occur throughout the area. These randomly oriented faults are commonly displaced by minor ductile mylonite zones. Most mylonites trend at 040° to 070° and dip both to the east and west. Although these ductile zones decrease significantly to the west away from the Virgin River Shear Zone, they are still present in the Clearwater Anorthosite Intrusion.

No direct field evidence for the Clearwater Fault (Scott, 1985) was found. Rock types north of this proposed fault, however, commonly lack blue quartz and contain much more anorthosite than rocks to the south. Rock types south of this line are dominated by blue quartz-bearing mixed quartzofeldspathic gneisses which contain virtually no anorthosite bands.

6. Conclusions

1) At least two types of anorthosite are present in the map area. An older type consists of fragments of anorthosite in an agmatitic unit. This agmatite unit is considered to be a major protolith of the mixed quartzofeldspathic gneisses. A younger type, which may be synchronous with the large Clearwater Anorthosite Intrusion, occurs as sheets within the gneisses.

2) The Clearwater Anorthosite Intrusion, a large cumulate body covering an area of about 10 by 20 km, shows evidence for multiple intrusion of anorthosite, leucogabbro and melagabbro.

3) The mixed quartzofeldspathic gneisses of the Western Craton near the Virgin River Shear Zone are considered to have developed through transposition of agmatized basic rock types that are cut by a variety of plutons.

4) The pelitic, psammopelitic and metavolcanic rocks contain metamorphic mineral assemblages that will allow the thermobarometric evolution of the terrain to be resolved.

5) Late granite sheets may reflect the influence of partial melting related to emplacement of the Clearwater Anorthosite Intrusion.

6) After the early folding episode (F_1), the terrain experienced static granulite facies metamorphism.

7) Extensive anatectic melting obscures and apparently postdates the F_2 folding.

8) The deformational effects of the Virgin River Shear Zone can be seen to the west in the Western Granulite Domain in a zone as much as 20 km wide.

Proposed Pb-Pb, Rb-Sr and Sm-Nd isotope geochemical research on the supracrustal rocks, anorthosite bodies and mixed quartzofeldspathic gneisses will be used to develop a crustal evolutionary history for this portion of the Western Granulite Domain.

7. Acknowledgements

We are grateful to Saskatchewan Energy and Mines for financial support. R. Macdonald and C.T. Harper coordinated, expedited and provided logistics for field work.

J.F. Lewry and M.E. Bickford provided stimulating discussions on the interpretations of field relationships. Lisa Campbell contributed many ideas and excellent field assistance. This research was also supported by a National Science Foundation Grant (EAR 87-20442) to Collerson and Bickford.

8. References

Bickford, M.E., Van Schmus, W.R., Macdonald, R., Lewry, J.F. and Pearson, J.G. (1986): U-Pb zircon geochronology project for the Trans-Hudson Orogen: current sampling and recent results; *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep. 86-4, p101-107.

Hoffman, P.F. (1988): United plates of America, the birth of a craton: Early Proterozoic assembly and growth of Laurentia; Annu. Rev. Earth Planet. Sci., v16, p543-603.

Hulbert, L. (1987): Investigation of mafic and ultramafic rocks, and platinum group element mineralization in northern Saskatchewan: preliminary findings; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p125-130.

Lewry, J.F. (1974): Structural relationships in the La Loche (north) map sheet and adjacent areas; *in* Summary Report of Field Investigations by the Saskatchewan Geological Survey, 1974; Sask. Dep. Miner. Resour., p46-55.

Lewry, J.F. and Collerson, K.D. (in press): The Trans-Hudson Orogen: extent, subdivision and problems.

Lewry, J.F. and Sibbald, T.I.I. (1977): Variation in lithology and tectonometamorphic relationships in the Precambrian basement of northern Saskatchewan; Can. J. Earth Sci., v14, p1453-1467.

__________ (1980): Thermotectonic evolution of the Churchill Province in northern Saskatchewan; Tectonophysics, v68, p45-82.

Scott, B.P. (1985): Geology of the Upper Clearwater River area; Sask. Energy Mines, Open File Rep. 85-2, 26p.

Sibbald, T.I.I. (1973): 74-B-NW: Mudjatik (nw), *in* Summary Report of Geological Investigations Conducted in the Precambrian Area of Saskatchewan, 1973; Sask. Dep. Miner. Resour., p35-42.

Sproule, J.C. (1941): Weitzel Lake, northern Saskatchewan; Geol. Surv. Can., Map 576A (with marginal notes), scale 1:253,440.

Project 8721

Geochemistry of Plutonic Rocks in the Central La Ronge Domain: Further Data for the Brindson Lake Pluton[1]

B.R. Watters[2]

Watters, B.R. (1988): Geochemistry of plutonic rocks in the central La Ronge domain: further data for the Brindson Lake Pluton; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

The geochemical study of plutonic rock units of the Central La Ronge Domain was continued during 1987-88 and data acquisition is almost complete. During this time, a further 320 samples from plutons in the Central La Ronge Domain were prepared and analyzed (by XRF methods) at the University of Regina. Specific intrusions represented by this group of samples are: Brindson Lake Pluton, Payn Creek Stock, Dreaver Lake Stock, Moir Lake Stock, Kruger Lake Pluton, Bernaski Bay Pluton, Hayman Lake Intrusion, Onipoowuk Pluton, Nipew Lake Basic Intrusion, Bassett Lake Granodiorite Intrusion and Bandur Lake Intrusion. Processing of these data is not yet complete and some geochemical characteristics of the Brindson Lake Pluton only will be discussed here.

A detailed geochemical and petrological study of the Brindson Lake Pluton constitutes a major component of the project and is being conducted in collaboration with C.T. Harper of the Saskatchewan Geological Survey. Recent analytical work has provided geochemical data for a further 160 samples from this intrusion, supplementing that previously available for 38 samples.

As described by Harper (1986), the Brindson Lake Pluton comprises a multiphase intrusion, each of the phases showing compositional zoning, ranging from simple concentric to asymmetric. Eight distinct phases have been identified on the basis of field and petrographic characteristics: Narrow Lake, Tower, Brindson, Northeastern, Southern, Dicus Lake, Severson Lake and Severson Leucogranite. Geochemical characteristics, as discussed below and in Watters (1987), substantiate this basic subdivision.

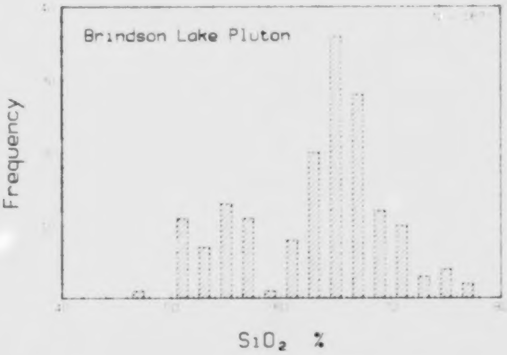

Figure 1 - SiO_2 histogram for the Brindson Lake Pluton, including all constituent phases.

Rock types making up the pluton range, broadly, from gabbro and diorite through monzonite, granodiorite and granite, to leucogranite. As illustrated by Figure 1, the overall wide compositional range of the pluton is reflected in SiO_2 contents that range from about 47 to 77 percent. The distribution of data in this histogram also confirms an overall compositional bimodality, as previously suggested (Watters, 1987) on the basis of more limited data. The distribution of SiO_2 in samples from individual major phases is shown in Figure 2 and it is apparent that the overall bimodal compositional character is due, to a great extent, to a similar bimodality within certain phases.

These compositional characteristics indicate that most phases fall into two groups: a smaller group having SiO_2 contents of about 50 to 57 percent ('low-Si' group) and a larger group having SiO_2 contents in the range 61 to 77 percent ('high-Si' group). As displayed by the histograms, a clear compositional break exists between the two groups, while two of the phases, the Brindson and Severson Leucogranite, include rocks of the relatively high silica group only.

The most reasonable explanation for these observations is that, throughout the emplacement history of the pluton, two magma sources were available and each intrusive phase was initiated with injection of 'low-Si' magma, to be followed by intermediate to acid 'high-Si' magma. Such a suggested sequence of intrusion for individual phases is generally supported by field evidence (Harper, pers. comm.) and is similar to the sequence of intrusion noted for the Star Lake Pluton (Thomas and Watters, 1987; Harper et al., 1986). Contamination by volcanic country rock may have played a minor role in producing the 'low-Si' early components of the phases, but the clear compositional break between the constituent groups, represented by few or no gradational

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(2) Department of Geology, University of Regina

types, can better be accounted for by multiple magma types.

Field evidence suggests that the major constituent phases may have been emplaced in the order: Tower, Dicus Lake, Southern, Brindson and Severson Leucogranite (Harper, pers. comm.). Figure 2 clearly shows the dominance of the 'low-Si' component in the Dicus Phase with a trend of progressively increasing 'high-Si' component through the Southern, Brindson and Severson Leucogranite phases. The lack of early 'low-Si' components in the Brindson and Severson Leucogranite phases suggests that, during the late stages of evolution of the pluton, only the 'high-Si' magma source was tapped. However, it cannot be ruled out that emplacement of this magma type did occur at a late stage but it is simply not present at the existing level of exposure.

Although the Tower phase, probably representing the earliest phase in the pluton, also displays bimodal compositional characteristics, it includes a dominance of 'high-Si' rock types and, therefore, does not conform to the general compositional trends as shown by later phases. As pointed out by Watters (1987), however, the component rock types of this phase show trace element characteristics that clearly separate it from other major phases of the pluton, suggesting that it may have evolved from a different magma batch and was, perhaps, also affected by contamination.

Certain trace element characteristics indicate that, with the emplacement of each successive phase, the overall composition of the magmas became progressively more fractionated (Watters, 1987), and major element data supports this suggestion. The mean concentrations of the major elements, as listed in Table 1, show a progressive change with the probable sequence of emplacement (with the exception of the Tower Phase). SiO_2, Al_2O_3, Na_2O and K_2O contents increase through the sequence, while MgO, CaO, FeO, MnO and TiO_2 show a steady decrease. A progressive fractionation could be expected to produce such compositional trends. It is not considered possible that the changes observed in the average composition of successive phases could be due solely to changes in the relative proportions of 'low-Si' and 'high-Si' components. While this is, no doubt, a contributing factor, the trace element data already reported (Watters, 1987) provide clear evidence to suggest that fractionation played an important role in the evolution of the magmas.

Furthermore, AFM plots show that, while the compositional fields of the Dicus, Southern, Brindson and Severson Leucogranite Phases overlap, there is a marked trend of fractionation with alkali enrichment and magnesium depletion through the intrusive sequence (Figure 3). Data for the Tower Phase have been plotted on a separate AFM diagram (Figure 4). All phases show strong calc-alkaline trends.

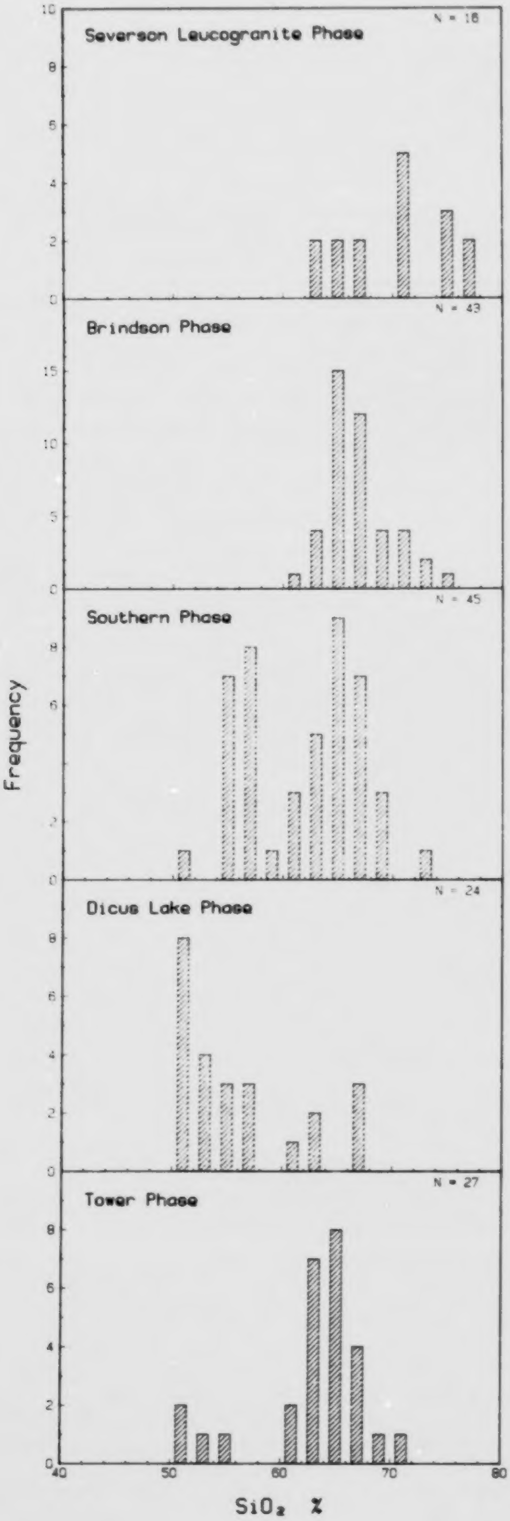

Figure 2 - SiO_2 histograms for major constituent phases of the Brindson Lake Pluton.

Table 1 – Average Major Element Composition of Major Intrusive Phases of the Brindson Lake Pluton

	TW	*DL*	*SO*	*BR*	*SL*
SiO_2	62.83	55.92	61.84	66.70	70.04
TiO_2	0.58	0.49	0.46	0.41	0.23
$A1_2O_3$	15.76	12.67	14.74	15.51	15.64
FeO*	4.93	6.60	5.00	3.52	1.99
MnO	0.90	0.13	0.09	0.06	0.04
MgO	4.40	10.54	5.92	2.73	1.60
CaO	5.47	8.43	6.42	4.32	2.46
Na_2O	4.30	3.39	4.24	4.82	5.68
K_2O	1.40	0.75	1.01	1.70	2.44
P_2O_5	0.20	0.20	0.14	0.15	0.12

Oxides in weight percent; FeO* = total Fe as FeO

TW	Tower Phase (n=27)
DL	Dicus Lake Phase (n=24)
SO	Southern Phase (n=45)
BR	Brindson Phase (n=43)
SL	Severson Leucogranite Phase (n=16)

Although less data are available for the Narrow Lake, Northeastern and Severson Lake Phases which Harper (pers. comm.) considers to be equivalents of the Tower, Brindson and Dicus Lake Phases, respectively, the available geochemical data strongly support these correlations. Rocks of the Northeastern Phase are of the 'high-Si' type with an average composition not significantly different from that of the Brindson Phase. The Severson Lake Phase comprises rocks that are low in SiO_2 (47 to 54 percent), high in MgO (14 to 29 percent) and can best be compared with the more basic members of the Dicus Lake Phase. Only two samples from the Narrow Lake Phase have been analyzed. These are of the 'low-Si' type and are not dissimilar to some of the more basic members of the Tower Phase.

References

Harper C.T. (1986): Bedrock geological mapping, Windrum Lake area (part of NTS 64D-4, 73P-16 and 74A-1); *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep.86-4, p8-18.

Harper, C.T., Thomas, D.J. and Watters, B.R. (1986): Geology and petrochemistry of the Star–Waddy Lakes area; *in* Clark, L.A. (ed.), Gold in the Western Shield; Can. Inst. Min. Metall., Spec. Vol. 38, p57-85.

Irvine, T.N. and Barager, W.R. (1971): A guide to the chemical classification of the common volcanic rocks; Can. J. Earth Sci., v8, p523-548.

Thomas, D.J. and Watters, B.R. (1987): The Star Lake Pluton and its gold mineralization – an overview; *in* Gilboy, C.F. and Vigrass, L.W. (ed.), Economic Minerals of Saskatchewan; Sask. Geol. Soc., Spec. Publ. 8, p54-57.

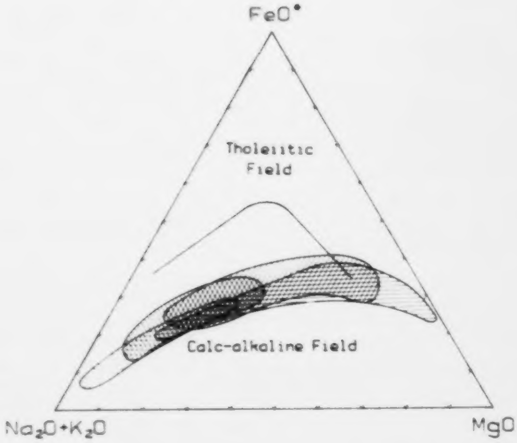

Figure 3 – AFM plot showing compositional fields for some major phases of the Brindson Lake Pluton. Key: ▧ Brindson Phase; ▨ Southern Phase; ≡ Dicus Lake Phase; ░ Severson Leucogranite Phase. Tholeiitic – calc-alkaline boundary from Irvine and Barager (1971).

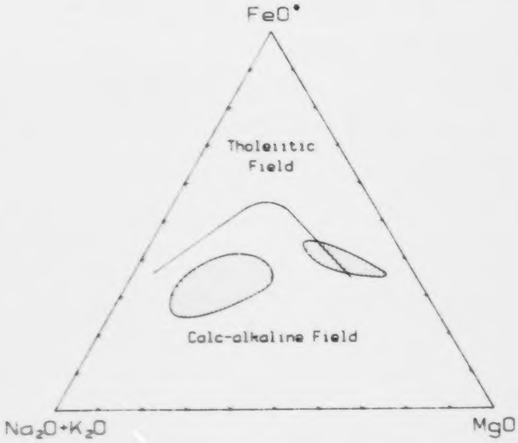

Figure 4 – AFM plot showing compositional field for the Tower Lake Phase of the Brindson Lake Pluton. Tholeiitic – calc-alkaline boundary from Irvine and Barager (1971).

Watters, B.R. (1987): Geochemistry of plutonic rocks in the Central Metavolcanic Belt, La Ronge Domain; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p69-73.

Project 8831

Geochemistry and Gold Metallogenic Studies, Sulphide-Pap Lakes Area[1]

D.C. Armstrong[2] and G.R. Parslow[3]

Armstrong, D.C. and Parslow, G.R. (1988): Geochemistry and gold metallogenic studies, Sulphide-Pap Lakes area; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

Investigations into the geochemistry and gold metallogenesis of the Sulphide-PAP Lakes area were continued during 1988 in the field areas described in the 1987 Summary of Investigations (Armstrong and Parslow, 1987). This report provides an update on work conducted over the winter of 1987-88 and includes the preliminary results of the regional geochemical investigation.

The study focuses on the central portion of the Stanley (west half) area (NTS 73P-7(W)) and supplements the 1:20,000 geological map of Sulphide Lake area produced by Sibbald (1987).

1. Objectives and Sampling Methodology

A regional geochemistry study was initiated in the Sulphide-PAP Lakes area during 1987 and continued in 1988. Major aims are to characterize the volcanic and plutonic rocks, to determine their probable geotectonic setting at the time of emplacement and to establish their relationship to the Central Metavolcanic Belt of the La Ronge Domain. It has been suggested that the Nut Bay Belt (which includes the Sulphide-PAP Lakes area) may represent a southern, dismembered continuation of the Central Metavolcanic Belt (Coombe et al., 1986; Thomas, 1987). Watters (1981, 1984, 1985, 1986) and Harper et al. (1986) have conducted extensive regional geochemical studies of the Central Metavolcanic Belt, mainly in the Star-Waddy Lakes area, but to date very little data are available for the Nut Bay Belt.

During the two field seasons a total of 503 samples were collected as outlined below. A sample location map is included in the accompanying map package.

a) Sulphide Lake area (215 samples prefixed 87SL and 88SL)

Samples comprise mafic to felsic metavolcanics and volcaniclastics, some associated intrusives and metasediments, plus mineralized samples and quartz veins taken from trenches. The samples of volcanics were taken in order to define geochemically different map units and enable discrimination of the tectonic setting of the area. It is felt that good coverage of Sibbald's (1986, 1987) units, as mapped, has been achieved. Mineralized samples and quartz veins taken from the Studer A, B and C zones and the Gem prospect are for ore petrography, fluid inclusion and stable isotope work.

b) Contact Lake Pluton (64 samples prefixed 87CL and 88CL)

This pluton, also referred to as the Little Deer Pluton, is a composite intrusion of gabbroic to granitic composition with an areal extent of 60 km^2. The margins of the pluton consist mainly of the most mafic (gabbroic) phases, while the central portions consist of the more felsic phases; most boundaries are gradational. Using the classification of Harper et al. (1986) for the Star-Waddy Lakes area, the Contact Lake Pluton appears to be a type 1 intrusive. These are early, synvolcanic, composite plutons showing moderate to strong zonation. The close proximity of the pluton to the gold occurrences in the Sulphide-PAP Lakes area suggests that it may have played an important role in the mineralization process, either as a direct source or as a heat engine for circulating fluids. The samples collected are to be used to characterize the pluton geochemically and establish the relationship of its different zones. A comparison with the chemistry of the volcanic sequence will be possible. It is also hoped to ascertain the role of the pluton in the genesis of the gold deposits.

c) PAP Lake zones (91 samples prefixed 87PA and 88PA)

Shear zone hosted gold mineralization occurs within the PAP zone dioritic to gabbroic sills. Samples were taken from this locality in order to allow comparison of the chemistry and mineralogy of sheared versus unsheared rock. It is also intended to determine if the PAP zone sills and the Contact Lake Pluton are comagmatic. Quartz vein samples were taken for fluid inclusion and stable isotope studies.

d) Drill core samples, Studer A, B and C zones, Sulphide Lake area (97 samples)

Altered and mineralized samples were taken from drill core in order to compare them with the equivalent unmineralized rocks collected during surface mapping. These will be used to test for the presence of enhancement and/or depletion haloes around the ore bodies and for ore petrography.

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[1] Project contracted to the University of Regina with funds provided under the Canada Component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89
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e) Other prospects (34 samples)

In addition to the main prospects of interest, samples were taken from the Main Camp (8), Turtle Lake (7), Jepson Lake (3), Ramsland (8), Preview (3), Clearwater A (3) and Discovery zone (2) showings.

f) U/Pb geochronology (2 samples)

U/Pb age determinations will be carried out by the University of Kansas on the two samples collected. Sample number HUD88-021 is a feldspar- and quartz-phyric crystal tuff collected from a small island in Sulphide Lake. HUD88-022 is a sample of the granitic phase of the Contact Lake Pluton. It is hoped that the dates gained will help to establish the relationship of the Sulphide-PAP Lakes area with the rest of the La Ronge metavolcanic belt.

g) Analysis of Samples

After conventional sample preparation, all of the 1987 whole rock samples were analyzed for major and trace elements and LOI. Major elements were determined using a Jarrell-Ash Model 975 Plasma Atomcomp Inductively Coupled Plasma Source Spectrometer (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, MnO and P_2O_5) and a Perkin-Elmer 603 Atomic Absorption Emission Spectrophotometer (Na_2O and K_2O); both facilities were provided by the University of Regina. Trace element concentrations (Zn, Cu, Ni, Rb, Sr, Y, Zr, Nb, Ba, U, Th, Pb, Ti, V and Cr) were determined using pressed powder pellets on a Phillips PW1400 X-Ray Fluorescence Spectrometer at Aston University, Birmingham, England.

2. Preliminary Interpretation of the Volcanic Rocks, Sulphide Lake Area

Thirty-five samples of basalts from the Sulphide Lake area were used for the discrimination plots presented here. The rocks were selected on the basis of SiO_2 <52 percent and screened to remove cumulates and metasediments.

The AFM diagram for major elements (Irvine and Baragar, 1971) and the $(Y+Zr)-(TiO_2 \times 100)-(Cr)$ trace element plot (Davies et al., 1979) can be used to distinguish between tholeiitic and calc-alkaline trends in volcanic rocks. When the Sulphide Lake basalts are plotted on an AFM diagram (Figure 1) they show a distinct tholeiitic character. On the $(Y+Zr)-(TiO_2 \times 100)-(Cr)$ discrimination plot (Figure 2) the basalts again clearly follow a tholeiitic trend.

The $K_2O-TiO_2-P_2O_5$ plot (Figure 3) devised by Pearce et al. (1974) to discriminate between oceanic and continental settings shows the Sulphide Lake basalts falling in the oceanic field with high concentrations of TiO_2

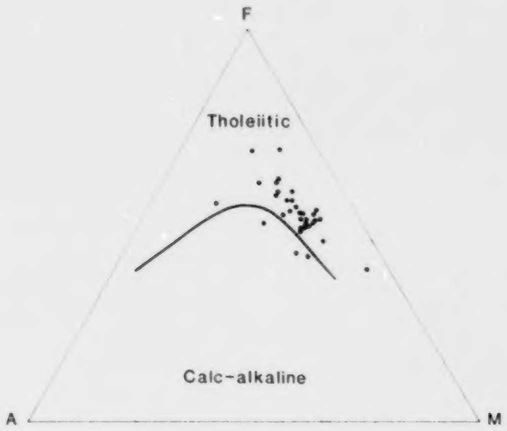

Figure 1 - AFM plot, Sulphide Lake area basalts. Field boundaries after Irvine and Baragar (1971).

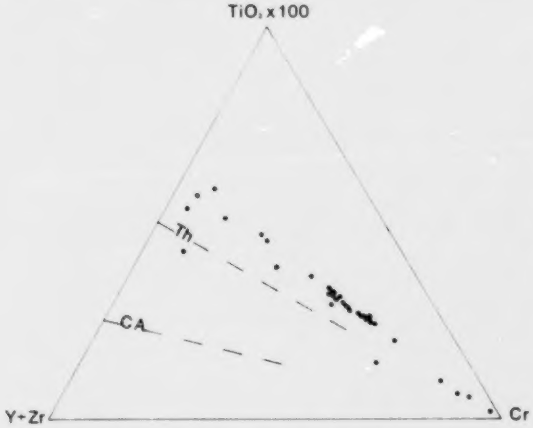

Figure 2 - $(Y+Zr)-(TiO_2 \times 100)-(Cr)$ plot, Sulphide Lake area basalts. Field boundaries after Davies et al. (1979).

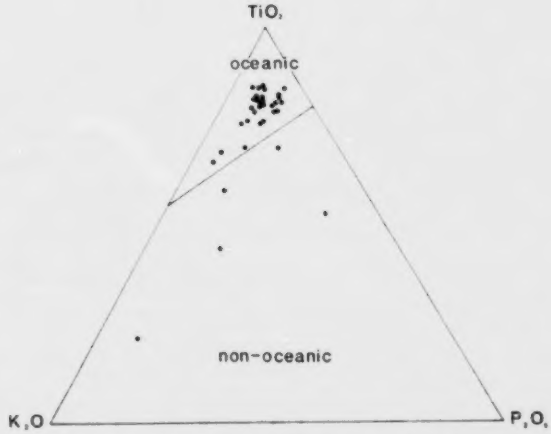

Figure 3 - $K_2O-TiO_2-P_2O_5$ discrimination plot, Sulphide Lake area basalts. Field boundaries after Pearce et al. (1974).

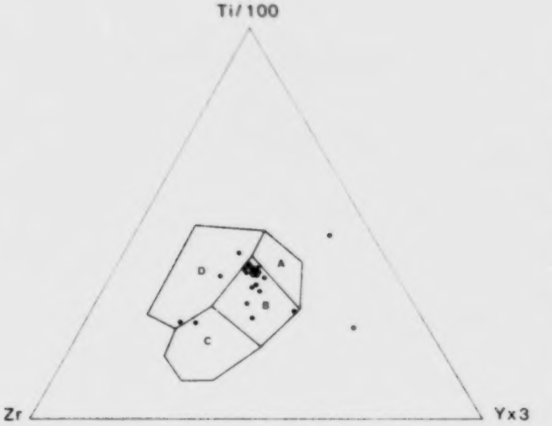

Figure 4 - (Zr) - (Ti/100) - (Y × 3) discrimination plot, Sulphide Lake area basalts. Field boundaries after Pearce and Cann (1973). A & B, low-potassium tholeiites; B, ocean floor basalts; B & C, calc-alkaline basalts; D, 'within-plate' basalts.

relative to K_2O and P_2O_5. The basalts in the study area are well discriminated on the Pearce and Cann (1973) (Zr) - (Ti/100) - (Y × 3) discrimination plot (Figure 4) with the majority of the samples clustering in the ocean floor basalt field. On the (Zr) - (Ti/100) - (Sr/2) diagram (Figure 5) of Pearce and Cann (1973) there is some scatter but the samples straddle the ocean floor basalt and low-potassium tholeiite field boundary. The scattering of the data points in this diagram is probably the result of strontium mobility during metamorphism.

The log Ti - log Zr diagram (Pearce, 1982) is used to discriminate arc lavas from 'within plate' lavas and also has a MORB field superimposed on the other two. On this diagram (Figure 6) the basalts plot within the MORB field and the majority of the intermediate and felsic samples fall within the arc lava field.

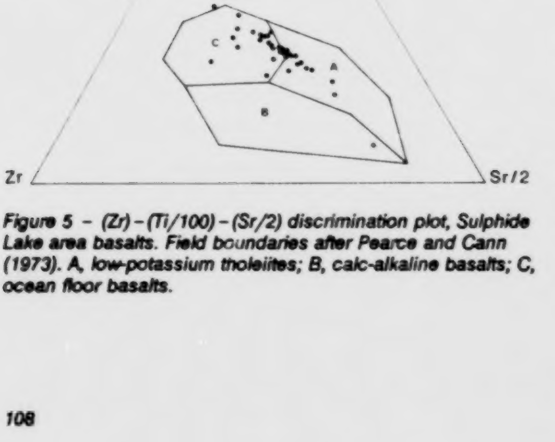

Figure 5 - (Zr) - (Ti/100) - (Sr/2) discrimination plot, Sulphide Lake area basalts. Field boundaries after Pearce and Cann (1973). A, low-potassium tholeiites; B, calc-alkaline basalts; C, ocean floor basalts.

From this combined evidence it appears that the Sulphide Lake area basalts exhibit a strong tholeiitic ocean floor character along with an island arc affinity. The suggestion that these rocks were erupted during the first stages of development of an arc sequence where ocean floor material is still a significant component of the rocks would be an explanation of the trends exhibited. The Sulphide Lake basalts could represent a structurally lower level of the Central Metavolcanic Belt sequence not exposed elsewhere.

When all the volcanic rocks in the Sulphide Lake area (66 samples) are taken together and plotted on the AFM diagram (Figure 7) the intermediate to felsic rocks (>52 percent SiO_2) display a calc-alkaline trend in strong contrast to the basalts. This calc-alkaline trend is also clearly displayed on the (Y + Zr) - (TiO_2 × 100) - (Cr) trace element plot (Figure 8) for all the volcanic rock samples. A clear compositional break between the basalts and the rest of the volcanics is also evident on this plot, indicating that the mafic and felsic volcanics in the area are not cogenetic and that it cannot be assumed that the felsic material was produced as a result of fractionation of the mafic material. There also appears to be a distinct lack of intermediate composition volcanics in the area.

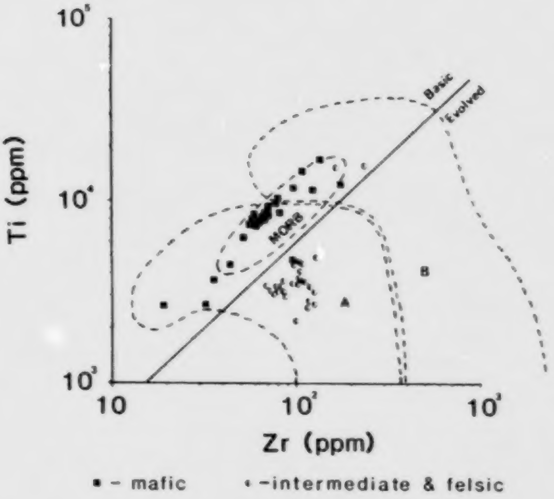

Figure 6 - Log - log Ti plot, Sulphide Lake area volcanics. Field boundaries after Pearce (1982). MORB, mid-ocean ridge basalt; A, arc lavas; B, 'within-plate' lavas.

Sibbald (1986) produced a generalized stratigraphic succession for the supracrustal rocks in the study area and on the basis of way-up criteria suggested that the sequence faces to the southeast. Since the rocks dip steeply northwest the sequence is overturned. The basalts in this study were collected mainly from unit 3 of Sibbald's stratigraphic succession. This unit is described

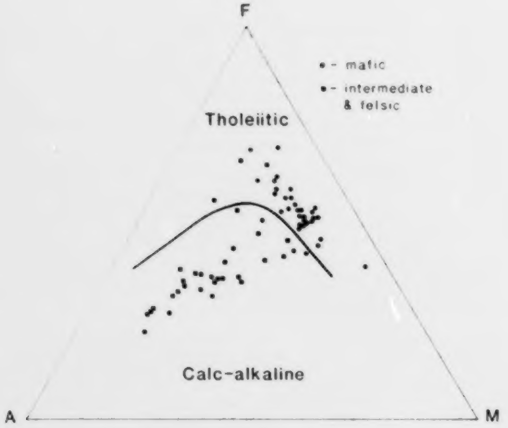

Figure 7 - AFM plot, Sulphide Lake area volcanics. Field boundaries after Irvine and Baragar (1971).

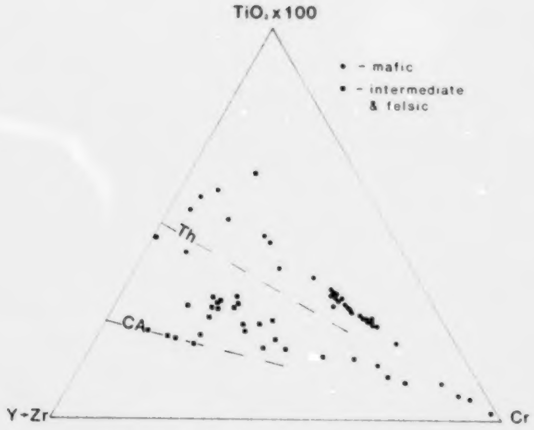

Figure 8 - (Y+Zr)-(TiO$_2$ × 100)-(Cr) plot, Sulphide Lake area volcanics. Field boundaries after Davies et al. (1979).

as a sequence of mafic pillowed flows with intercalated mafic sills (Sibbald, 1986). In contrast, the intermediate to felsic material was taken from unit 4 of the succession. This unit comprises felsic to intermediate metavolcaniclastics with minor pillowed flows and interlayered pelitic metasediments, in part carbonaceous and sulphidic (Sibbald, 1986). Therefore the two rock types have a spatial separation and on this basis can not be assumed to have the same origin.

One explanation for the geochemical patterns displayed by the rocks could be that the basalts represent early arc material, which retains a strong oceanic character, whereas the more felsic material was erupted later when the island arc was more fully developed. This would also fit with Sibbald's (1986) suggestion of a southeast younging direction. Another possibility is that the basalts represent ocean floor material totally unrelated to the later calc-alkaline material, with the two units becoming juxtaposed at a later date.

3. Preliminary Interpretation of the Plutonic Rocks, Sulphide Lake Area

Numerous bodies of gabbroic to granitic composition intrude the supracrustal sequence of metavolcanic and metasedimentary rocks in the study area. The largest intrusion in the area is the composite Contact Lake Pluton which, as previously mentioned in this report, ranges in composition from granitic in the centre, through granodioritic to diorite/gabbro at the margins.

An AFM plot (Figure 9) of samples collected from all zones of the pluton in 1987 clearly shows the calc-alkaline nature of the pluton. The granitic phases show a tightly constrained compositional trend with typical alkali enrichment, whereas the intermediate to mafic phases show much more scatter, indicating a greater degree of compositional variation. This is consistent with the field observation that the outer zones of the pluton are highly composite and multiphase in character.

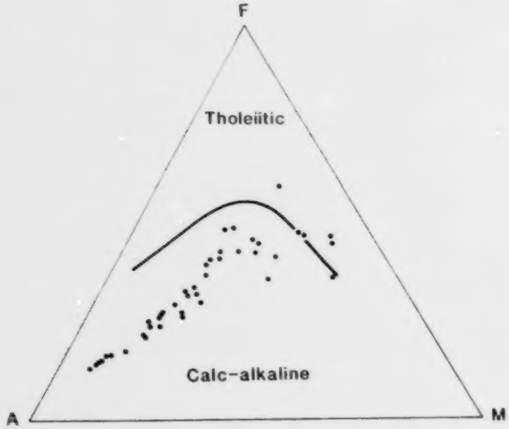

Figure 9 - AFM plot, Contact Lake Pluton samples. Field boundaries after Irvine and Baragar (1971).

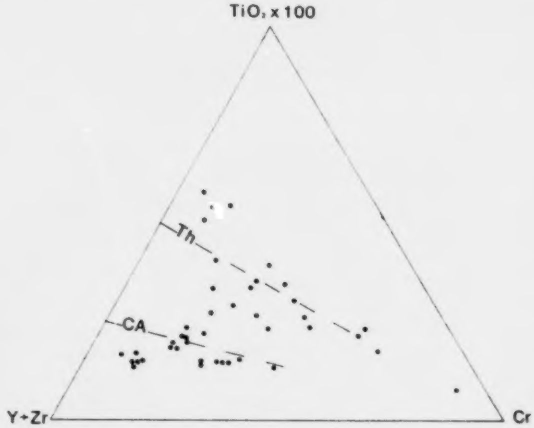

Figure 10 - (Y+Zr)-(TiO$_2$ × 100)-(Cr) plot, Contact Lake Pluton samples. Field boundaries after Davies et al. (1979).

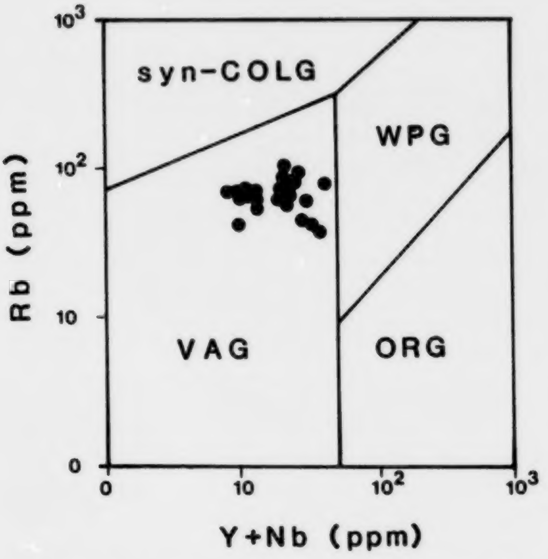

Figure 11 – Rb-Y+Nb discrimination plot, Contact Lake Pluton 'granitic' rocks. Field boundaries after Pearce et al. (1984). VAG, 'volcanic arc' granites; ORG, 'ocean ridge' granites; WPG, 'within-plate' granites; syn-COLG, syn-collision granites.

The calc-alkaline character of the pluton is also evident on the (Y + Zr) – ($TiO_2 \times 100$) – (Cr) plot (Figure 10). Despite the scatter of data points, it can be seen that the pluton evolved from an early tholeiitic trend through to a later calc-alkaline trend.

Work by Pearce et al. (1984) has demonstrated that it is possible to discriminate between 'granitic' rocks (>56 percent SiO_2) from different tectonic settings on the basis of trace element relationships. Applying these discrimination criteria, the zoned Contact Lake Pluton clearly falls within the volcanic arc granite field (Figure 11). This is entirely consistent with the idea of the intrusive rocks being produced as a result of calc-alkaline plutonism during the later stages of arc development.

The setting and character of the Contact Lake Pluton appears, from the work done by Watters (1986) on other plutons in the Central Metavolcanic Belt, similar to other intrusives in the La Ronge Domain.

4. Preliminary Interpretation of the Fluid Inclusion Studies

Representative samples of vein quartz from different prospects and different vein generations within each prospect were collected to provide material for a fluid inclusion study. It is hoped the study, when completed, will provide information on temperature of ore deposition and composition of the mineralizing fluids. It will also form the basis of a comparison between the different styles of mineralization in the project area.

Thirty specimens collected in 1987 have been prepared as 0.3 mm thick, doubly polished quartz wafers and a Linkham TH600 heating and freezing stage is in use for thermometric measurements.

To date only a petrographic examination of the inclusions has been completed. The quartz in all the wafers studied so far consists of a mosaic of small grains, indicating a history of repeated movement along the vein, which resulted in crushing and some recrystallization of the quartz. The quartz contains abundant inclusions, most of which are very small (5 to 10 μm across) which is typical of gold-bearing quartz veins (Roedder, 1984). Many are too small to be used for measurements but some that are amenable to heating and freezing studies have been identified. No inclusions seen can be interpreted as primary in origin; however, this is not thought to be a problem, as it has been suggested (Roedder, 1984) that gold is usually introduced by late fluids after the bulk of the quartz has crystallized.

The most common occurrence of the inclusions is as trails along healed fracture surfaces, sometimes cross-cutting several grains or contained within a single grain. Three-dimensional clusters are also present.

A complex assemblage of several types of inclusions has been observed. The most common inclusion types are:

1) monophase gaseous CO_2 inclusions;
2) two phase (liquid plus vapour) dilute aqueous inclusions;
3) immiscible liquid (liquid$_1$ plus liquid$_2$ plus vapour) inclusions, which contain an aqueous solution surrounding a CO_2-rich liquid, which in turn surrounds a CO_2-rich vapour bubble; and
4) occasional two-phase (liquid plus solid) aqueous inclusions containing daughter crystals.

Such a diverse assemblage could be produced as a result of unmixing of an originally homogeneous fluid due to temperature and pressure reduction, possibly as a result of boiling. A full interpretation should be possible when thermometric measurements have been completed.

A trial bulk inclusion analysis was undertaken on six samples of quartz to gain information on the CO_2/H_2O ratio of the fluids. The samples were coarsely crushed, hand picked and cleaned to ensure purity, degassed and then decrepitated under vacuum. The released gases were passed through a manometer to measure gas pressure.

The non-aqueous condensible phases of the first sample were sent to a gas chromatograph and output indicated that CO_2 constituted 99 percent of this fraction. On this basis it was assumed that all manometric readings for CO_2+ represented CO_2. The results are given in Table 1.

From these preliminary results it can be seen that the samples associated with the larger prospects (e.g., PAP SW zone, Studer C zone) do appear to have a higher

Table 1 – CO_2/H_2O Ratios of Quartz Inclusion Fluids

	Sample	*mole x 10^{-6}/g*			
Prospect Name	*No.*	*N.C.*	*CO_2^+*	*H_2O*	*CO_2/H_2O*
PAP SW Zone	87PA0043	0.24	0.76	3.87	0.20
	87PA0006	0.19	3.12	3.28	0.95
Studer C Zone	SU87/41 (@ 32.5 m)	0.28	0.91	2.74	0.33
	87SL0085	0.40	1.16	7.56	0.15
Clearwater A	87CW0001	0.18	0.33	6.80	0.05
Turtle Lake	87TL0002	0.08	0.10	2.46	0.04

N.C. non-condensible gases (H_2, Ar_2, O_2, N_2, CH_4, etc.)
CO_2^+ CO_2 (>99 percent) plus traces of other condensible gases at −196°C

CO_2/H_2O ratio than the smaller prospects. The CO_2/H_2O ratio could be an indicator of the grade of mineralization, as the presence of CO_2-rich fluids has been reported from many gold localities. Further analyses will be undertaken in an attempt to ascertain if the CO_2/H_2O ratio and CO_2 yield have any relationship to the gold grades in the various prospects.

5. Acknowledgements

Once again the senior author would like to thank Tom Sibbald (Saskatchewan Energy and Mines) and Rob Chapman (SMDC) for encouragement, assistance and many lively discussions throughout the summer's work. Both authors would also like to thank Andrea McDougall (field assistant) for her enthusiastic help during the field season and assistance with sample preparation at the University of Regina, Bill Gaskarth (University of Birmingham, U.K.), Sierd Eriks (SMDC), and Andrew Gracie (Resident Geologist, Saskatchewan Energy and Mines, La Ronge). Thanks also to Vern Studer and Gill Williams without whom the summer's work at Sulphide Lake would not have been the same!

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6. References

Armstrong, D.C. and Parslow, G.R. (1987): Gold metallogenic studies, Sulphide and PAP Lakes area; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p52-57.

Coombe, W., Lewry, J.F. and Macdonald, R. (1986): Regional geological setting of gold in the La Ronge Domain, Saskatchewan; *in* Clark, L.A. (ed.), Gold in the Western Shield; Can. Inst. Min. Metall., Spec. Vol. 38, p26-56.

Davies, J.F., Grant, R.W.E. and Whitehead, R.E.S. (1979): Immobile trace elements and Archean volcanic stratigraphy in the Timmins mining area, Ontario; Can. J. Earth Sci., v16, p305-311.

Harper, C., Thomas, D.J. and Watters, B.R. (1986): Geology and petrochemistry of the Star–Waddy Lakes area, Saskatchewan; *in* Clark, L.A. (ed.), Gold in the Western Shield; Can. Inst. Min. Metall., Spec. Vol. 38, p57-85.

Irvine, T.N. and Baragar, W.R.A. (1971): A guide to the chemical classification of the common volcanic rocks; Can. J. Earth Sci., v8, p523-548.

Pearce, J.A. (1982): Trace element characteristics of lavas from destructive plate boundaries; *in* Thorpe, R.S. (ed.), Andesites; J. Wiley and Sons, Chichester, p525-547.

Pearce, J.A. and Cann, J.R. (1973): Tectonic setting of basic volcanic rocks determined using trace element analysis; Earth Planet. Sci. Lett., v19, p290-300.

Pearce, T.H., Gorman, B.E. and Birkett, T.C. (1974): The $TiO_2-K_2O-P_2O_5$ diagram: a method of discriminating between oceanic and non-oceanic basalts; Earth Planet. Sci. Lett., v24, p419-426.

Pearce, J.A., Harris, N.B.W. and Tindle, A.G. (1984): Trace element discrimination diagrams for tectonic interpretation of granitic rocks; J. Petrol., v25, p956-983.

Roedder, E. (1984): Fluid Inclusions; Mineral. Soc. Am., Reviews in Mineralogy, v12, 644p.

Sibbald, T.I.I. (1986): Bedrock geological mapping, Sulphide Lake area (part of NTS 73P-7); *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep. 86-4, p63-64.

________ (1987): Bedrock geology, Sulphide Lake area (part of NTS 73P-7); 1:20,000 scale prelim. map *with* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4.

Thomas, D.J. (1987): Gold deposits of the La Ronge Domain; Geol. Assoc. Can./Mineral. Assoc. Can., Joint Annu. Meet., Saskatoon, Field Trip Guidebook No. 4, 70p.

Watters, B.R. (1981): Geochemistry of metavolcanic rocks in the La Ronge Domain; *in* Summary of Investigations 1981, Sask. Geol. Surv., Misc. Rep. 81-4, p34-37.

________ (1984): Geochemical patterns for metavolcanic rocks in the La Ronge Domain; *in* Summary of Investigations 1984, Sask. Geol. Surv., Misc. Rep. 84-4, p88-91.

________ (1985): Geochemistry of metavolcanic and plutonic rocks, Star Lake and Waddy Lake area; *in* Summary of Investigations 1985, Sask. Geol. Surv., Misc. Rep. 85-4, p28-34.

________ (1986): Geochemistry and geochronology of metavolcanic and plutonic rocks in the Central Metavolcanic Belt; *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep. 86-4, p76-83.

Project 8804

U-Pb Geochronology and Isotopic Studies of the Trans-Hudson Orogen in Sasaktchewan[1]

M. E. Bickford[2], K. D. Collerson[3] and J. F. Lewry[4]

Bickford, M.E., Collerson, K.D. and Lewry, J.F. (1988): U-Pb geochronology and isotopic studies of the Trans-Hudson Orogen in Saskatchewan; *in* Summary of Investigations 1988; Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

Last year (Bickford et al., 1987), we reported the results of age determinations by the U-Pb zircon method for some of the samples collected in 1984, 1985 and 1986. This report describes the results of age determinations carried out since last year's report from these previously collected samples. In the second part of the report we outline the principal goals of a new two-year research program initiated this year under U.S. National Science Foundation funds and Saskatchewan Energy and Mines support, and document new samples collected under this program during the summer.

1. New Age Data

a) Churchill Platform (Mudjatik and Western Granulite Domains)

HUD-85-10 is a sample of a quartz-feldspar-biotite-pyroxene augen gneiss associated with boudinaged pyroxenitic dykes and broad open folds. The sample was collected on a small island in the west end of Careen Lake (NTS 74C-16; 56°59'N, 108°11'W). Four fractions of zircons from this sample provide a cluster of analytical points that collectively yield a regression age of 2384 ± 410 Ma (Figure 1A). One fraction in the +60 size range yielded a greater $^{207}Pb/^{206}Pb$ age than the other fractions, perhaps indicating some inherited component. If this fraction is excluded from the regression, an age of 2250 ± 59 Ma is obtained (Figure 1B). Analysis of additional fractions is in progress. This sample has clearly been affected by the widespread 2.0 to 2.1 Ga high-grade metamorphism that has formed metamorphic zircons in most rocks studied from the Churchill Platform (Bickford and Collerson, 1987).

HUD-85-12 is a sample of felsic orthopyroxene gneiss (charnockitic gneiss) collected on Jim Lake in the Mudjatik Domain (NTS 74B-3; 56°13'N, 107°12'W). The only two fractions of zircon so far analyzed from this sample indicate an age of 1928 ± 39 Ma (Figure 2). Interpretation of these data is difficult at this stage of the analysis; if the 1928 Ma age stands as more fractions are done, it will be very significant, for it is suggestive of an early Hudsonian event.

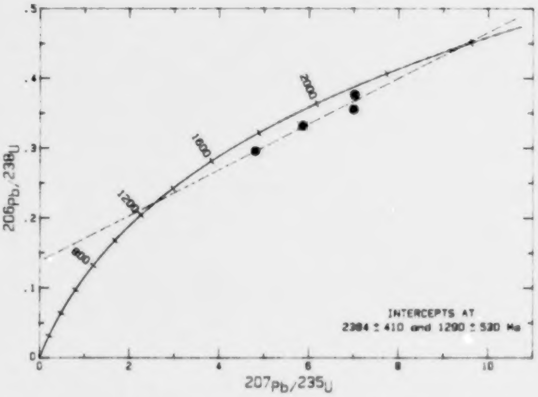

Figure 1A - Preliminary concordia diagram for zircon fractions from augen gneiss (HUD-85-10), Mudjatik Domain

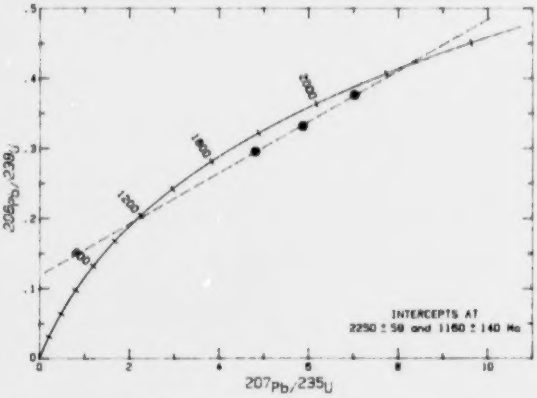

Figure 1B - Preliminary concordia diagram for selected zircon fractions from augen gneiss (HUD-85-10), Mudjatik Domain

HUD-85-15 is a fine-grained felsic rock that is probably a completely recrystallized felsic volcanic rock, and was collected in the eastern part of Segment Lake (NTS

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(1) Funded partly in joint venture by the U.S. National Science Foundation and the Saskatchewan component of the Canada - Saskatchewan Subsidiary Agreement on Mineral Development 1984 - 89

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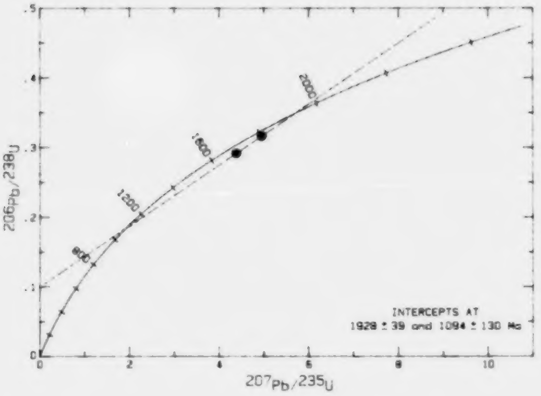

Figure 2 – Preliminary concordia diagram for zircon fractions from charnockitic gneiss (HUD-85-12), Mudjatik Domain

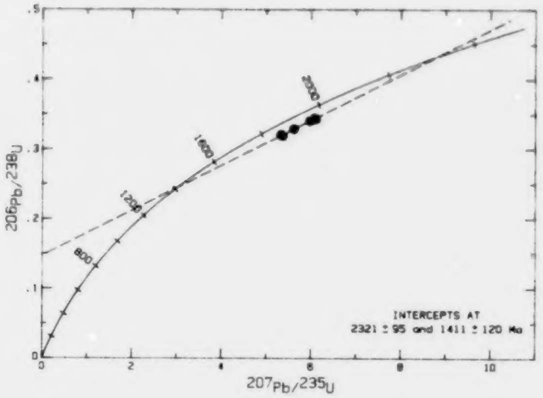

Figure 4 – Preliminary concordia diagram for zircon fractions from grey tonalitic gneiss (HUD-85-18B), Peter Lake Domain

74B-6; 56°17'N, 107°08'W). Preliminary data (Figure 3), based on analysis of two zircon fractions, give an age of about 1821 ± 12 Ma. As with HUD-85-10, interpretation based on only two fractions is difficult; if this age can be confirmed with analysis of more fractions, it will be the first documentation of a "Hudsonian" rock of probable supracrustal origin on the Churchill craton in Saskatchewan. The only sample, other than HUD-85-10 and HUD-85-12, that has yielded a Hudsonian age is the 1820 ± 19 Ma Junction granite (Bickford and Collerson, 1987; Bickford et al., 1987).

b) Peter Lake Domain

In last year's report (Bickford et al., 1987) we presented data from a sample of granitic gneiss (HUD-85-19) collected from a small island in Compulsion Bay of Wollaston Lake (NTS 64E-14; 57°48'N, 103°14'W). Six fractions of zircon from this sample yielded an age of 2188 ± 46 Ma, and a Sm-Nd analysis by K.D. Collerson yielded a model age of 2851 Ma, indicating that the rock sampled is of Archean age but was remelted or totally recrystallized about 2.2 Ga. Here we report additional age determinations from rock samples in this area.

HUD-85-18B is a sample of grey megacrystic tonalitic gneiss collected from a small island in Compulsion Bay, Wollaston Lake, at a site within a few hundred metres of the HUD-85-19 site (see above). The grey gneiss is cut by mafic dykes. This sample yielded a complex zircon suite composed of large dark somewhat corroded zircons and an abundant population of clear euhedral zircons. On the basis of our experience with similar complex zircon populations from samples farther west in the Churchill platform, we expected the large dark zircons to yield Archean ages. Regression of six fractions, however, yields the array shown in Figure 4, and indicates an age of 2321 ± 95 Ma; the large dark fractions appear to be part of the array.

HUD-85-18A is a sample of a fine-grained red granitic gneiss that probably cuts both the grey gneiss (above) and the mafic dykes. Three fractions of zircons from this

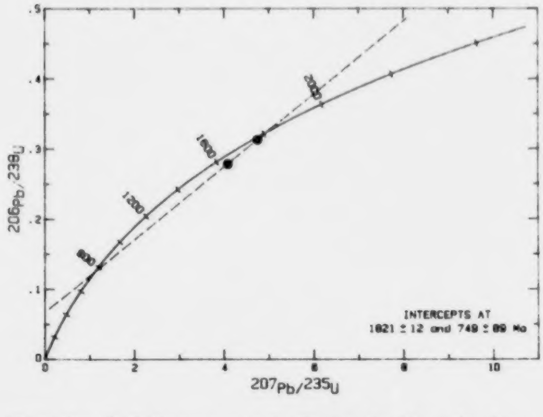

Figure 3 – Preliminary concordia diagram for zircon fractions from fine-grained felsic gneiss (HUD-85-15), Mudjatik Domain

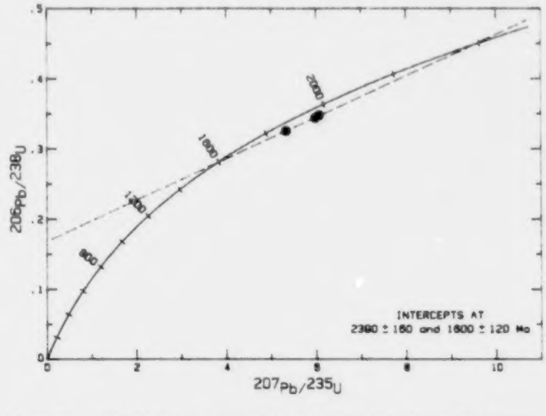

Figure 5 – Preliminary concordia diagram for zircon fractions from pink granitic gneiss (HUD-85-18A), Peter Lake Domain

gneiss yield a regression age of 2390 ± 160 Ma (Figure 5).

It seems likely that the arrays of zircon fractions from these two samples represent various mixtures of Archean zircons with metamorphic overgrowths. Taken together, the results from HUD-85-19, -18A, and -18B may be interpreted to indicate that the effects of the approximately 2.1 to 2.0 Ga high-grade metamorphism are indeed pervasive and widespread. The newly analyzed samples (HUD-85-18A and -B) are, like HUD-85-19, probably of Archean age but have undergone high-grade metamorphism about 2.1 to 2.0 Ga. Metamorphic zircons yielding ages of about 2.1 to 2.0 Ga have been found throughout the Churchill Platform (Bickford and Collerson, 1987; Bickford et al., 1987).

HUD-85-16 is a sample of the Horton Island granite collected from a small island in Nekweaga Bay in the southwestern part of Wollaston Lake (NTS 64E-13; 57°49'N, 103°45'W). As this granite body cuts the Wollaston Group, its age places a lower limit on the age of these metasedimentary rocks. Four zircon fractions yield the array shown in Figure 6. Regression of the data indicate an age of 1840 ± 29 Ma. The Horton Island granite is clearly a Hudsonian intrusion.

c) Kisseynew Domain and Hanson Lake Block

We report preliminary results on samples from two granitic plutons in the eastern part of the Trans-Hudson Orogen which were collected in the summer of 1986 by two of the authors (MEB and JFL) in company with R. Macdonald.

HUD-86-10 is a sample of the Mari Lake Granodiorite collected on McCormick Lake (NTS 63N-4; 55°08'N, 101°50'W). The rock sampled is strongly lineated and may be from the core of a gneissic dome. It had been speculated that this rock might be Archean basement, but the preliminary age data do not support this. The one zircon fraction analyzed so far yielded a ^{207}Pb/^{206}Pb age of 1814 Ma and U-Pb ages indicating that it is moderately discordant. It is likely that the age will be in the 1850 to 1860 Ma range. Analyses of additional fractions are underway.

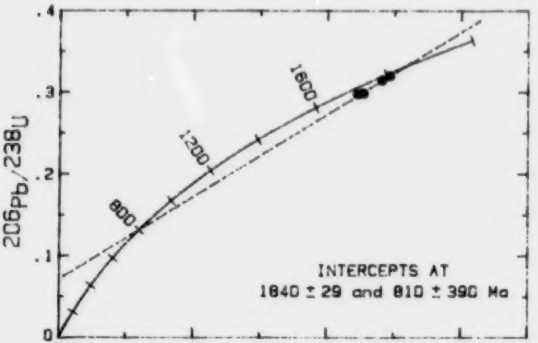

Figure 6 – Preliminary concordia diagram for zircon fractions from Horton Island granite (HUD-85-16), Peter Lake Domain

HUD-86-14 is a sample of the granodiorite of Jackpine Lake in the Hanson Lake area. The sample was collected on the shore of Jackpine Lake (approx. 54°44'N, 102°50'W). The rock is strongly foliated and contains many inclusions. It is also cut by numerous large pegmatite dykes. Our sample was collected from an inclusion-free area where there are no pegmatites. Two zircon fractions produced ^{207}Pb/^{207}Pb ages of 1870 and 1859 Ma. Analysis of several more fractions will likely yield data indicating an age of about 1870 Ma. Last year (Bickford et al., 1987) we reported the age of HUD-85-15, a granodiorite exposed on the shore of Bertram Bay in Hanson Lake (only a few kilometres from the Jackpine Lake collecting area), as 1844 ± 12 Ma.

2. New Isotopic Studies in the La Ronge and Glennie Domains

A major part of the new research program funded by the United States National Science Foundation is the isotopic study of rocks in the La Ronge and Glennie Domains. This work is designed to determine the sources of magmas and the nature of the lower crust beneath the Hudsonian orogenic plutons and supracrustal rocks. The recent work of J.R. Chiarenzelli, a University of Kansas doctoral student (Chiarenzelli and Chiarenzelli, 1986; Chiarenzelli et al., 1987) has shown that parts of the transition region between the La Ronge Domain and the adjacent Glennie Domain are underlain by Archean basement, with ages in the 2.5 Ga range. Hudsonian orogenic rocks in this region are in thrust contact with the Archean basement, which is interpreted as the northwestern edge of the Superior craton. Thus, much of the Hudsonian orogenic material in the La Ronge Domain and the Glennie Domain may similarly have been thrust upon Archean basement rocks during collisional orogenesis.

Our plan is to determine the isotopic compositions of Archean basement and both plutonic and supracrustal orogenic rocks. We will also analyze late undeformed leucogranites and pegmatites that cut the deformed orogenic rocks, using them as probes of the underlying crust. An implicit assumption is that these late intrusions have been generated in the lower crust and will carry the geochemical and isotopic signature of that crust. We plan to study the Sm-Nd and Rb-Sr systematics of total rock samples and the isotopic systematics of Pb from feldspars. These isotope systems should clearly carry the signature of the magma source from which the rocks crystallized.

Interpretation of the isotopic data will require that the ages of the rocks be known. In much of our sampling, we have collected geochemical samples from basement or orogenic rocks which were previously dated by zircon studies, and where age data were not available we collected new samples for zircon age determination. During examination of the late leucogranites and pegmatites that intrude these rocks, we collected sufficient material for dating by U-Pb analysis of zircon or monazite. The ages of these late undeformed leucogranites and pegmatites will be an important byproduct of this research, for these ages should effectively constrain the time of deformation.

The results of this study should document the isotopic characteristics of Archean basement and Hudsonian orogenic rocks. Previous studies (Chauvel et al., 1987) have indicated that the Hudsonian orogenic rocks are mostly of juvenile derivation; our studies will either confirm that finding or possibly show that some of the Hudsonian rocks were derived from or contaminated with older Archean continental crust. Additionally, the analysis of the late leucogranites and pegmatites may reveal whether orogenic rocks, including perhaps those of juvenile origin, are underlain by Archean basement. We believe these studies will yield important data regarding the relative amounts of recycled older crust and new orogenic material derived from the mantle by subduction of intervening oceanic lithosphere during closure. These proportions will have an important impact upon calculation of rates of crustal generation (e.g., Patchett and Arndt, 1986).

To initiate this research, samples were collected from two general localities this summer:

a) Hunter and Campbell Bays, Lac la Ronge

This sampling area (NTS 73P-2, between 55°07' and 55°15'N and 104°30' and 104°40'W) lies in the southern part of the Iskwatikan Complex of the Glennie Domain, and comprises a domal exposure of Archean basement (J.R. Chiarenzelli and J.F. Lewry, pers. comm.). The following samples were collected:

HUD-88-1 is strongly foliated tonalitic or granodioritic gneiss. Chiarenzelli (pers. comm.) has found an Archean age for this sample. Because the rock has been dated, we took only a very fresh geochemical sample.

HUD-88-2 is aplitic leucogranite which clearly intrudes the tonalitic gneiss of HUD-88-1. The leucogranite is faintly foliated, but undeformed relative to the tonalite. We took both zircon and geochemical samples of this rock.

HUD-88-3 is a massive quartz-K-feldspar-biotite pegmatite that cuts Archean basement. Chiarenzelli (pers. comm.) has determined an age for the pegmatite of 1788 Ma from analysis of monazite. We took a fresh geochemical sample.

HUD-88-4 is feldspar from a pegmatite that crosscuts porphyroblastic gneiss.

HUD-88-5 is foliated tonalitic gneiss from the region in which Chiarenzelli has found Archean ages. Because this rock has not been directly dated, we took both a zircon and a geochemical sample.

HUD-88-6 is K-feldspar from a pegmatite that cuts the gneiss of sample HUD-88-5.

HUD-88-7 is K-feldspar from a pegmatite that cuts "Guncoat-type" gneisses.

HUD-88-8 is an aplite/pegmatite dyke that cuts strongly foliated tonalitic gneiss similar to HUD-88-5. The aplite/pegmatite contains abundant fresh allanite which we propose to date by U-Pb methods.

HUD-88-9 is a sample of the tonalitic gneiss described above that is cut by the aplite/pegmatite of HUD-88-8. We took both zircon and geochemical samples.

HUD-88-10 is a geochemical sample of a garnetiferous augen gneiss for which Chiarenzelli (pers. comm.) has determined an Archean age.

HUD-88-11 is a zircon and geochemical sample of very fresh hornblende-quartz-plagioclase-biotite-K-feldspar granodiorite that is only weakly foliated. This sample should be representative of the interior of the Iskwatikan Complex and will presumably be Archean.

HUD-88-12 is a sample of an undeformed pink granite dyke that cuts a grey composite foliated fine-grained to mylonitic gneiss. We collected both zircon and geochemical samples.

HUD-88-13 is a sample of the grey gneiss described above. We took both zircon and geochemical samples.

b) Stanley Mission Road area

This sampling locality lies along Highway 102 north of La Ronge and the Stanley Mission Road (NTS 73P-2, -3, -6 and -7, between 55°07' to 55°30'N and 104°40' and 105°30'W). These samples were taken from entirely within the orogenic Hudsonian domain. Their analysis should reveal whether the orogenic terrain here is underlain by older Archean crust. The samples are:

HUD-88-14 and HUD-88-15 are, respectively, a zircon/geochemistry sample of an undeformed pegmatite that cuts quartz diorite and a geochemical sample of the quartz diorite. We did not collect a zircon sample of the quartz diorite because such a sample had been previously collected for age dating (HUD-84-33). The samples were collected along Highway 102 about 5 km north of La Ronge.

HUD-88-16 is a zircon/geochemistry sample of foliated grey granodiorite or tonalite. This sample was collected on the Stanley Mission Road 20.8 km northwest of the junction with Highway 102.

HUD-88-17 is a zircon/geochemistry sample of an undeformed pegmatite that cuts the grey tonalitic gneiss of HUD-88-16.

3. Acknowledgments

Financial support was provided by grants from the National Science Foundation (US$200,000; March 1988 to March 1990) to Bickford and Collerson for the new isotopic studies, as well as continued geochronology.

Additional support was provided by Saskatchewan Energy and Mines through a contract under the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-1989, which provided interim funding pending extension of the U.S. funding as well as logistic support in the field. The authors are grateful for useful discussions with R. Macdonald and W.R. Van Schmus.

4. References

Bickford, M.E. and Collerson, K.D. (1987): The Trans-Hudson Orogen: pre-orogenic assembly and orogenic thermotectonism; Geol. Assoc. Can./Mineral. Assoc. Can., Joint Annu. Meet., Saskatoon, May 25-27., Prog. Abstr., v12, p25.

Bickford, M.E., Van Schmus, W.R., Collerson, K.D. and Macdonald, R. (1987): U-Pb zircon geochronology project: new results and interpretations; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p76-79.

Chauvel, C., Arndt, N.T., Kielenzcuk, S. and Thom, A., (1987): Formation of Canadian 1.9 Ga old continental crust: (I) Nd isotopic data; Can. J. Earth Sci., v24, p396-406.

Chiarenzelli, J.R. and Chiarenzelli, V.R. (1986): Nistowiak Lake tectonic studies (part of NTS 73P-7); *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep. 86-4, p65-71.

Chiarenzelli, J.R., Lewry, J.F. and Landon, M. (1987): Bedrock geology, Iskwatikan Lake area: evidence for Hudsonian juxtaposition of Proterozoic and Archean rocks along a ductile detachment surface; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p46-51.

Patchett, P.J. and Arndt, N.T. (1986): Nd isotopes and tectonics of 1.9-1.7 Ga crustal genesis; Earth Planet. Sci. Lett., v78, p328-338.

Building Stone Investigations[1]

P. Guliov

Guliov, P. (1988): Building stone investigations; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

The use of indigenous stone for construction in Saskatchewan historically has been confined largely to glacial erratics (fieldstone) of sedimentary, igneous and metamorphic origins. The earliest applications frequently involved the use of undressed or partially dressed fieldstone in wall construction. Later, with the discovery of extensive glacially deposited dolomite boulder fields near Saskatoon, that material gained extensive use in construction on the campus of the University of Saskatchewan. The boulders were split to various sizes and dressed into rough blocks. The dolomite erratics have been used in construction on the campus since about 1911. Use of this local material has declined with a gradual depletion of the deposits and the rise of labour costs. The greater proportion of stone construction in the province now relies on a wide variety of imported materials ranging from rough slab veneer to rough blocks, ashlar, polished exterior and interior veneer, and large polished blocks for monuments.

Stone quarrying, whether for monuments, construction, aggregate, lime production or metallurgical use, takes place in all provinces except Prince Edward Island and Saskatchewan. Despite the vast region of Precambrian rocks in northern Saskatchewan and the extensive Ordovician dolomites exposed along the southeastern margin of the Shield, the region has been largely neglected in terms of stone resource development. Inaccessibility, remoteness from markets, limited demand and a shortage of financial resources have contributed to this neglect. Despite these difficulties, limited background technical and market investigations were conducted from time to time during the late seventies and early eighties by the province.

Demand for dimension stone in North America has experienced strong growth over the past eight years and shows no signs of diminishing. Much of the demand originates in the United States where the use of polished stone panels as functional and decorative interior and exterior wall cladding, as well as flooring for office and commercial buildings, is steadily gaining in popularity. Modern sophisticated European stone cutting and polishing technology is making inroads into the Canadian stone industry. This has resulted in reduced production costs. These factors, combined with a strong U.S. dollar, are advantageous for Canadian producers (Vagt, 1988). Many provinces, as a result of the favourable market conditions, have initiated aggressive investigations of building stone resources. Many of these are being conducted as projects under Federal-Provincial Mineral Development Agreements throughout Canada.

While the scope of Saskatchewan's building stone investigations under MDA is limited by modest funding, some significant work has been conducted during the past several years. This has stimulated industry interest in Saskatchewan stone and generated significant additional investigative work under Federal Government and private funding.

1. Investigations

The earliest serious attempt to promote the quarrying and marketing of Saskatchewan stone was made by the Department of Northern Saskatchewan in the late seventies and early eighties. During that period, market studies as well as limited engineering tests and product marketing tests were conducted for rough building stone from the Stanley Mission area. Ordovician dolomites in the Deschambault Lake area were also considered as a potentially marketable construction material. In 1984 and early 1985, Saskatchewan Energy and Mines conducted preliminary investigations of the Ordovician dolomites along the Hanson Lake Road between Deschambault Lake and Limestone Lake. Investigations during the same period included the gabbroic rocks of the Neyrinck Lake Pluton, the pink granites of the Jan Lake Pluton and the grey granites of the Ismond Lake Pluton. The Jan Lake granites were excluded from further investigation for technical reasons. Work on the Ismond Lake granite was inconclusive due to the small area examined in relation to the total extent of the plutonic body and it remains open to further investigation. The Neyrinck Lake gabbro and the Ordovician dolomites were judged to warrant further investigation based on technical and market criteria.

Following more detailed considerations of the two prospective areas, a two-phase project was conducted under the Federal-Provincial Mineral Development Agreement, comprising:

1) core drilling and testing the Ordovician dolomites in 1985; and
2) bulk sampling the dolomites and the Neyrinck Lake diorite and gabbro in 1986-87 as a preliminary step to the production of a promotional sample display package and brochure for potential developers.

Both projects had succeeded in stimulating industry to carry out additional investigations prior to the completion of the promotional package. At present, dolomite leases and a granite exploration permit are held under the Quarrying Regulations, 1957. Field investigations

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(1) Project funded under the Saskatchewan component of the Canada-Saskatchewan Mineral Development Agreement 1984-89

and experimental work are being conducted on both projects by industry through partial Federal funding by NEDSA[2], and material from both areas has stimulated considerable local and international interest.

During 1988, Saskatchewan Energy and Mines continued the building stone reconnaissance in the La Ronge Domain under the Mineral Development Agreement. About two weeks were spent in June examining granites of the Wilson Lake Pluton and part of the Bridgeman Lake Pluton by controlled traversing at 100 m and 250 m spacing, respectively. A report on this phase of the work is presented separately (M.W. Thomas, this volume).

In mid-September of 1988, a second phase of the reconnaissance concentrated on parts of several other plutons in the area, specifically:

1) Kruger Lake (quartz diorite - granite);
2) Bernaski Bay (quartz monzonite - granite);
3) Bassett Lake (gabbro);
4) Bervin Lake (quartz diorite - granite); and
5) Brindson Lake Pluton (gabbroic bodies).

Approximately 6 km of traversing were conducted in each area. Generally, traverses were located in areas judged to be of prime interest based on published reports and personal communication with field personnel. Technical field observations made from the perspective of stone quarrying and utilization, combined with sample analyses, will be used to focus future work of a more detailed nature.

2. Reference

Vagt, O. (1988): Stone; *in* Canadian Minerals Yearbook 1987, Review and Outlook; Energy Mines and Resources Canada, Mineral Rep. 36, p60.1-60.14.

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[2] Northern Economic Development Subsidiary Agreement

Geological Assessment of Building Stone Potential, Wilson Lake and Bridgeman Lake Plutons (NTS 73P-16 and 73P-10)[1]

M.W. Thomas[2]

Thomas, M.W. (1988): Geological assessment of building stone potential, Wilson Lake and Bridgeman Lake Plutons (NTS 73P-16 and 73P-10); *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

In June 1988, R.W. Shirkie Geological Consultants Ltd. was contracted by the Industrial Minerals Section of Saskatchewan Energy and Mines to conduct a field assessment of two granitoid plutons in northern Saskatchewan, namely the Wilson Lake and Bridgeman Lake Plutons, for their building stone potential. The appraisal of these two plutons is the latest in a number of evaluations of prospective building stone sites that have been conducted in recent years, with the goal of developing a domestic building stone industry in Saskatchewan.

The Wilson Lake and Bridgeman Lake areas are located in the south-central part of the Precambrian Shield in northern Saskatchewan (Figure 1). Wilson Lake is situated in NTS area 73P-16, 40 km northeast of the town of Missinipe; access via Highway 102 is possible to within about 2 km of the Wilson Lake area. Bridgeman Lake is situated in NTS area 73P-10, 10 km south of Missinipe and about 4 km east of Highway 102.

Both areas have recently been geologically mapped at 1:20,000 scale by D.J. Thomas (1985, 1987).

The building stone potential of rocks in northern Saskatchewan has, until very recently, not been seriously considered. However, the construction of numerous all-weather roads through the north has radically improved accessibility, making the idea of quarrying prospective localities much more economically attractive. The Neyrinck Lake Pluton, located 7 km north of Wilson Lake, is undergoing evaluation as a quarry site, and Ordovician Red River dolomites at Limestone Lake on the Hanson Lake road (Highway 106) are presently being developed. Neither the Wilson Lake nor Bridgeman Lake Pluton has been evaluated for its building stone potential prior to this investigation.

The immediate objectives of this project were to conduct geological mapping in the two selected areas from the perspective of building stone evaluation, and to make qualitative judgements as to the suitability of the rocks for building stone. An estimate of the available volume of material to the base level of the local topography was also to be made. Five days were spent in each of the two areas conducting the field investigations. A temporary grid was established in each area for mapping control, using compass and metric hip chain. Crosslines were only established in areas of adequate bedrock exposure, as discerned from examination of 1:50,000 scale vertical airphotos of each area. No effort was made to locate and map outcrops situated between crosslines; however, all major outcrops were examined.

1. Wilson Lake Area (NTS 73P-16)

a) Physiography

The Wilson Lake grid area is characterized by broad bedrock uplands separated by commonly linear muskeg-covered lowlands and masked with a veneer of bouldery glacial drift less than 2 m thick. Bedrock exposures through the drift are locally fairly common but generally less than 50 m^2 in size. Outcrop comprises less than 5 percent of the grid area. Local relief on the uplands rarely exceeds 3 m. Topographic contours in the grid area, taken from the 1:50,000 scale topographic map (NTS 73P-16, Settee Lake), indicate that elevations range from 15 to 35 m above the level of Wilson Lake (Figure 2).

b) Rock Types

Within the grid area, the Wilson Lake Pluton is a homogeneous massive leucocratic granitoid with 10 percent or less biotite ± hornblende. Accessory minerals include rare magnetite and finely disseminated pyrite. The rocks are generally medium grained and commonly display a subporphyritic texture, with subhedral to euhedral, equant to lath-shaped feldspar phenocrysts up to 5 mm in diameter scattered in the equigranular groundmass. Sporadic mafic clots occur locally. No penetrative foliations or lineations are present in the Wilson Lake granitoid. Compositionally, the pluton ranges from granite to granodiorite (Thomas, 1985).

Rock colour varies from very light pink to light pinkish grey to light grey to medium grey. The pink variants appear to be slightly finer grained and biotitic, whereas the medium grey varieties are hornblendic, with combined hornblende plus biotite comprising 10 percent of the rock. Overall colour is controlled by the feldspar, which ranges from pink to pinkish grey to greenish grey, and to a lesser extent by the percentage of mafic minerals.

Other than the predominant occurrence of the grey hornblendic granitoid in the south part of the grid area, none of the above-mentioned variations are mappable,

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(1) Project contracted to R.W. Shirkie Geological Consultants of Regina, with funds provided under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89

(2) R.W. Shirkie Geological Consultants Ltd., Regina, Saskatchewan

and no contacts or crosscutting relationships were observed. From the building stone perspective, the pluton can be considered compositionally and texturally homogeneous.

White vein quartz is very common in the mapped area and occurs as irregular patches, stockworks, tension gashes and planar veins, and is generally associated with shear zones. Granitic pegmatite patches occur with the extensive quartz veining in one locality.

Very fine grained grey to brown mafic to intermediate dykes were observed at five separate outcrops in the grid area. They range in thickness from less than 1 cm to greater than 10 m and have sharp and generally shear-bounded contacts with the granite. All five dykes strike east-west and have steep to subvertical dips.

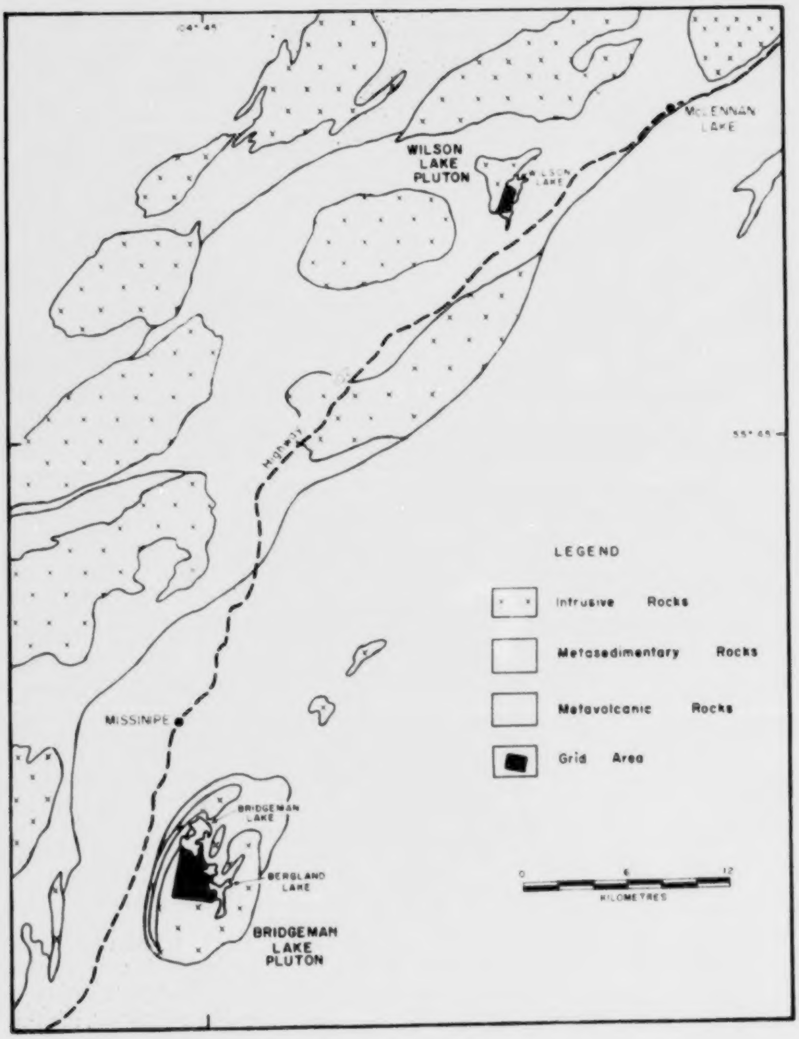

Figure 1 - Location and regional geology of the Wilson Lake and Bridgeman Lake areas (geology simplified from Lewry and Slimmon, 1985).

c) Structure

The Wilson Lake Pluton is massive and unfoliated within the grid area. However, shear zones and related non-penetrative structures are very common in all but a few of the outcrops examined. The shears vary from narrow discrete zones of anastomosing shear laminations in a massive but locally microfractured granite, to intensely ribboned and mylonitized zones flanked by envelopes of coarsely flasered granite gneiss greater than 10 m thick. The shears are commonly accompanied by quartz veining, pyrite and/or epidote mineralization, chloritized mafic minerals, gouge, and reddening of the granite adjacent to the shears. A weak quartz rodding is discernible in some shear zones. Crosscutting shears and offsetting relationships are exposed locally.

Orientations of shears and associated quartz veins appear to have a preferred east-west strike and subvertical dip (Figure 3). This orientation is shared by the trend of the five dykes observed in the grid area and is also subparallel to the trend of a major airphoto lineament which crosscuts the grid (Thomas, 1985).

Most joints evident in the Wilson Lake area are subvertical to steeply dipping, planar to slightly curviplanar structures. They range from single widely spaced master joints continuous over the extent of an outcrop, to *en echelon* joints less than 1 m long occurring in zones usually less than 50 cm thick. On outcrop scale, systematic orthogonal joint sets can occasionally be determined; at one location, two separate sets of orthogonal joints are evident. Other than a possible weak preferred orientation to the north-northwest, these subvertical joints possess widely variable strikes (Figure 4). If two separate orthogonal joint sets are regionally developed throughout the pluton, this lack of preferred orientation is not a surprising result.

Subhorizontal sheeting is prevalent on some outcrops. Spacing is generally about 50 cm and the sheet planes are lenticular. Due to the low topographic relief in

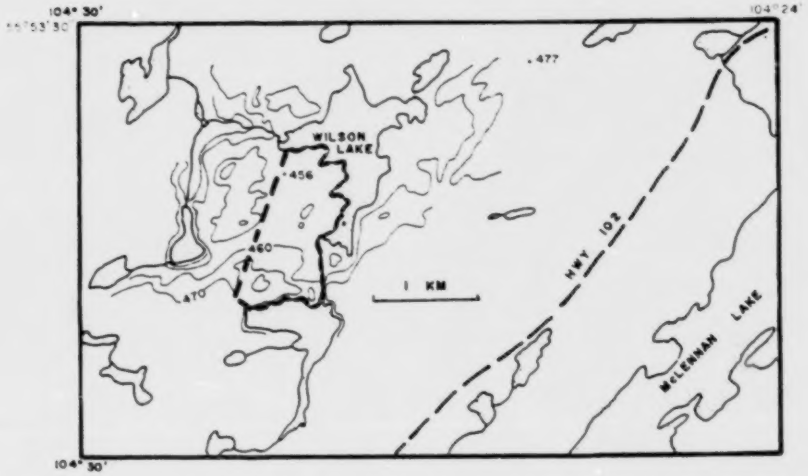

Figure 2 - Topographic map, Wilson Lake area. Contours are in metres above sea level at 10 m intervals (from 1:50,000 scale topographic map, Settee Lake, NTS 73P-16).

the area, these structures are very hard to identify.

Moderately dipping joints occur sporadically in the grid area. Spacing and regularity of these joints is unknown since they usually occur in outcrop as a single joint plane.

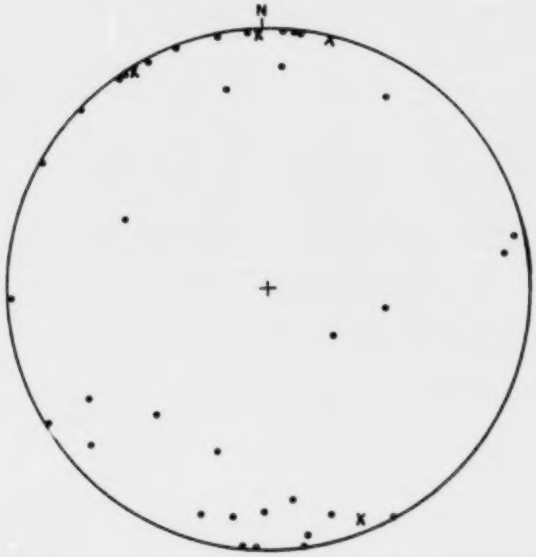

Figure 3 - Equal-area projection of poles to quartz veins and shears (dots; 35 measurements), and mafic to intermediate dykes (crosses; 4 measurements), Wilson Lake area.

2. Bridgeman Lake Area (NTS 73P-10)

a) Physiography

The Bridgeman Lake area is characterized by extensive bedrock uplands flanking a central drift- and muskeg-covered lowland trough extending south from Bridgeman Lake (Figure 5). The regional slope is from south to north and elevations in the south are up to 90 m above the level of Bridgeman Lake. The uplands expose extensive and continuous bedrock outcrops with intervening areas of thin, bouldery glacial drift. Local relief on upland ridges includes cliffs as much as 10 m high. Exposure is most abundant in the high ground to the south and is progressively more drift- covered on the lower ground to the north. Outcrop constitutes about 15 percent of the grid area; all but the northeast corner of the grid has recently been burned by forest fire and resulting exposures are exceptionally clean.

b) Rock Types

The most common rock exposed at Bridgeman Lake is a light pink to pinkish grey, fine-grained, equigranular hornblende ± biotite aplogranite exhibiting a conspicuous sugary texture. Mafic minerals usually com-

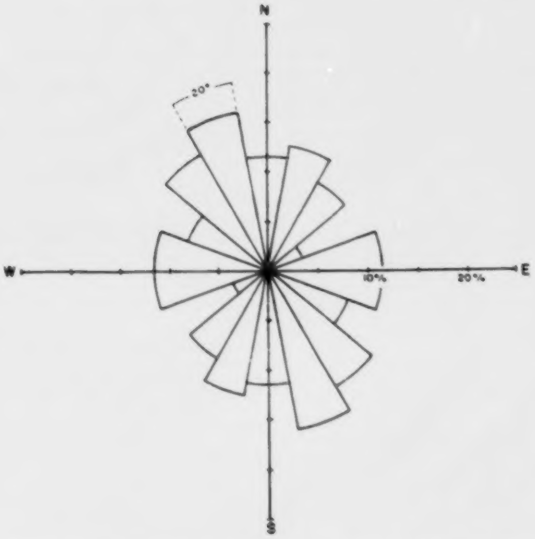

Figure 4 - Rose diagram of strikes of 140 subvertical to steeply dipping joints, Wilson Lake area.

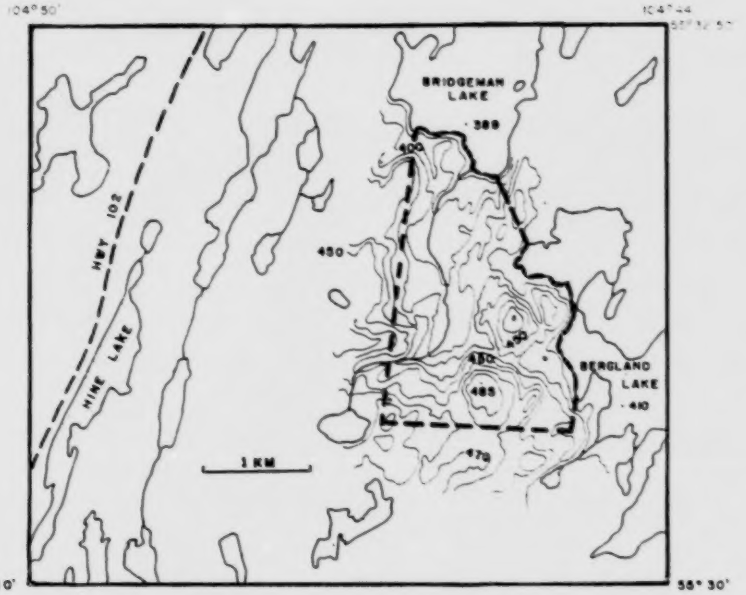

Figure 5 - Topographic map, Bridgeman Lake area. Contours are in metres above sea level at 10 m intervals (from 1:50,000 scale topographic map, Otter Lake, NTS 73P-10).

prise up to 5 percent of the rock and are aligned in a weak foliation. Ragged hornblende clots up to 10 mm long occur locally. Fine-grained amphibolite "fish", usually occurring in bunches, are scattered throughout. The "fish" range in size from thin wisps a few centimetres long to rare 50 cm thick bands traceable along strike for tens of metres. Isolated light pink euhedral microcline megacrysts occur rarely in the aplogranite groundmass. These crystals lie oblique to the foliation and are commonly poikilitic, containing scattered fine mafic inclusions. A more prominent feature of the aplogranite is a migmatitic banding defined by bright pink medium- to coarse-grained granitic leucosome. The leucosome generally comprises about 15 percent of the rock and mostly occurs in 2 to 20 cm thick *lit-par-lit* bands parallel to foliation. Irregular crosscutting leucosome is also common. Quartz veining and pegmatitic bands are in places associated with leucosome. In spite of the migmatitic layering, and the sporadic appearance of amphibolite "fish" and microcline megacrysts, the aplogranite is homogeneous on a scale greater than 100 cm.

Along the eastern edge of the grid area, a light pink medium-grained and weakly foliated microcline megacrystic hornblende ± biotite granite is exposed. Hornblende is locally altered to epidote and/or chlorite. The rock differs from the aplogranite in having a coarser

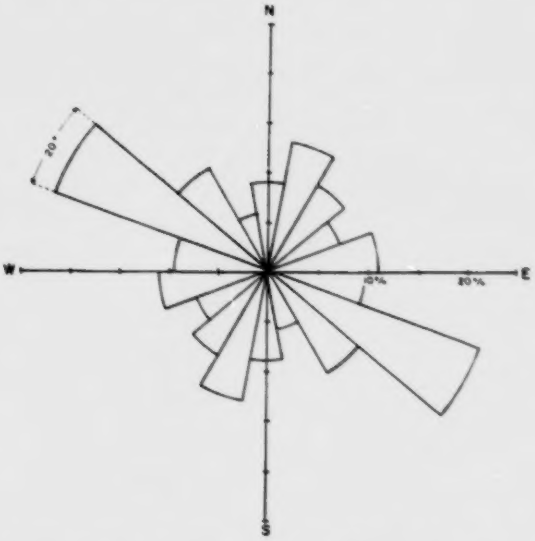

Figure 6 - Rose diagram of strikes of 136 subvertical to steeply dipping joints, Bridgeman Lake area.

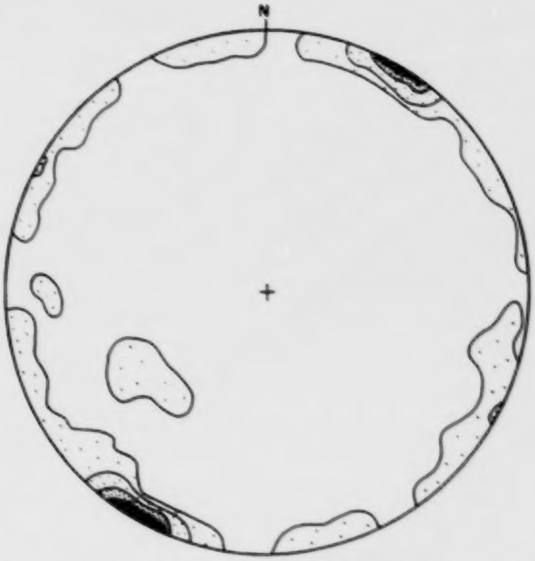

Figure 7 - Contoured equal-area projection of poles to steeply and moderately dipping joints (167 measurements; dip greater than 33°), Bridgeman Lake area. Contours at 10, 7.5, 5 and 2.5 percent per 1 percent area. Contours drawn by the "free-counter method" described in Turner and Weiss (1963, p. 62).

grained granitic texture, and in lacking leucosomal banding. Combined mafics are locally more abundant, approaching 10 percent of the rock. The microcline megacrysts are also more common and slightly larger in this unit, but are still euhedral, poikilitic, unoriented and widely scattered in the medium-grained groundmass. Contact relationships between this unit and the aplogranite were not observed in the grid area. In the northern part of the grid, the distinction between the two is tenuous.

c) Structure

All rocks exposed in the Bridgeman Lake area display some type of penetrative planar fabric. The aplogranite has a weak foliation and parallel migmatitic banding, and the microcline megacrystic granite is generally foliated. These S-surfaces have steep dips and strike north-northwest. Other minor structural elements observed locally include a second steeply dipping foliation acutely oblique to S_1, and one instance of quartz rodding. No mesoscopic folds were observed.

Jointing is the only other conspicuous structural element in the study area. Two types of joints predominate: subhorizontal and subvertical. Subhorizontal jointing or sheeting is extremely well developed and is easily observed due to the considerable vertical relief and the fire-cleaned nature of the outcrops. The sheets generally range from 10 cm to greater than 200 cm in thickness and are lenticular in shape, with the joint planes curving and branching from one another. The sheets seem to roughly parallel gentle topographic variations.

Subvertical jointing, although occurring in a variety of strike orientations, is most commonly aligned in a northwesterly direction (Figures 6 and 7). Subvertical joints orthogonal to this northwest trend parallel the dominant northeasterly foliation/banding trend in the rocks. They are usually less continuous and more poorly developed than the northwesterly joints, as the granites do not easily cleave along banding. Spacing of subvertical joints commonly ranges from 20 cm to over 400 cm, and averages about 100 cm.

Moderately dipping joint sets occur sporadically in the area. Observed joints are generally spaced regularly 1 to 3 m apart and are fairly continuous across an outcrop. These joints appear to have a preferred northwest strike and moderate northeast dip (Figure 7).

3. Discussion and Conclusions

Important geological considerations to be addressed in the initial evaluation of a prospective quarry site include:

1) *Lithological and Textural Homogeneity:* Homogeneity is desirable to ensure a consistent product over the life of the quarry. Inhomogeneities such as dykes and veins normally constitute waste rock which adds to quarrying cost.

2) *Mineralogical Stability:* The stone product must be able to withstand the rigours inherent in the use to which it is put. If it breaks down or changes in some way with time, its strengths and/or aesthetic characteristics may be adversely affected and thus reduce its value as a building material.

3) *Structural Characteristic:* Cleavages, joints and shears largely dictate the size and shape of extractable quarry blocks. Such structural elements should be as regular and widely spaced as possible for the most economic use of rock and limitation of waste. Some structural elements, such as sheeting and irregular jointing, are considered to be mainly due to surface weathering and unloading of the rock body; these structures are commonly observed to decrease in intensity and even disappear with depth (Currier, 1960). Intensity of geological structures such as foliations or shear zones are not as likely to vary with normal quarrying depths.

In addition to geological factors, the practical considerations of site accessibility, thickness of overburden, ease of quarrying operations, and reserves of extractable material should also be assessed in the early stages of site evaluation, since problems in any one of these areas could easily render an otherwise favourable deposit uneconomic.

a) Wilson Lake Area

Within the grid area at Wilson Lake, the granitoid itself displays fairly good lithological and textural homogeneity; colour changes from light pink to light grey, slight grain size change, and the presence or absence of hornblende were the only variations noted. However, the quartz veins and basic to intermediate dykes found intruding the pluton detract from this homogeneity. Considering the common occurrence of these features, particularly the quartz veins, in this poorly exposed area, these inhomogeneities may be very abundant and would likely produce abundant waste material in quarrying operations.

Mineralogically, the presence of disseminated pyrite in the granite is worrisome. Although not always the case (Currier, 1960), sulphides commonly oxidize and produce rusty spots and streaks on the finished surface of the stone.

Structurally, the largely random orientation of subvertical joints and the common occurrence of shear zones at Wilson Lake indicates that extractable blocks would likely be small and irregularly shaped. The shear-related effects such as microfracturing, flasered foliation zones and gouge would also introduce waste material into the quarry process.

The proximity of the Wilson Lake Pluton to Highway 102 and the presence of considerable volumes of rock (approximately 6 million m^3 above the level of Wilson Lake) in thinly drift-covered bedrock uplands are all features which favour the Wilson Lake area as a quarry site. However, the geological character of the pluton indicates the likelihood of abundant waste rock and small irregular block size. In addition, the presence of pyrite could render unsuitable an otherwise acceptable product.

b) Bridgeman Lake Area

At Bridgeman Lake, two main rock types are exposed: an aplogranite and a megacrystic granite. The very light pink aplogranite, with its fine-grained sugary texture and migmatitic banding, predominates and is quite homogeneous on a metre scale. Variations include structure and amount of leucosome, and the sporadic presence of amphibolite "fish", microcline megacrysts and quartz veins. Excluding the quartz veins which are relatively rare, none of these heterogeneities would likely constitute waste rock. Other than the rare quartz vein and pegmatite dyke, the microcline megacrystic granite exposed along the east side of the grid area is also homogeneous.

Both rock types appear to be composed entirely of silicates and thus should possess quite adequate mineralogical stability. The sporadic epidote/chlorite alteration of hornblende in the megacrystic rock should not present a problem in this regard. The aplogranite seems noticeably more friable than the megacrystic granite when worked with a hammer (A. Douma, pers. comm.). This may be either a surface weathering phenomenon or related to the conspicuous sugary texture of the rock. In either case, it could adversely affect the strength and durability of the stone.

Structurally, the two units are characterized by a generally strong northeasterly-trending penetrative foliation or related planar structure, extensive subhorizontal sheeting, and a well-developed northwesterly-trending subvertical joint set. The intersection of these three structural elements would produce regularly shaped blocks and facilitate quarrying with minimal waste material. Potential block size would likely be smallest near surface because of the generally close-spaced nature of the sheeting. In many granite quarries, this structure increases in spacing with depth (Currier, 1960), so that block thickness increases as the quarry is developed.

The Bridgeman Lake area is 4 km from Highway 102 and thus quite accessible. The presence of huge bedrock uplands with a thin, discontinuous veneer of glacial drift indicates extensive reserves of easily quarriable material (approximately 57 million m^3 above the level of Bergland Lake). Also, since the grid area represents only a portion of the Bridgeman Lake Pluton (Thomas, 1987), potential reserves are enormous. The presence of more than one granite variety in the same area could provide an added dimension to the quarry site.

4. Acknowledgements

Discussions with Paul Guliov of Saskatchewan Energy and Mines and Al Douma of Michelangelo Marble and Granite Co. Ltd. of Saskatoon concerning various aspects of the stone industry are gratefully acknowledged.

5. References

Currier, L.W. (1960): Geological appraisal of dimension stone deposits; U.S. Geol. Surv., Bull. 1109, 78p.

Lewry, J.F. and Slimmon, W.L. (1985): Compilation bedrock geology, Lac la Ronge, NTS area 73P/73I; Sask. Energy Mines, Rep. 225 (1:250 000 scale map with marginal notes).

Thomas, D.J. (1985): Geological mapping, Roundish - Bervin Lakes area (part of NTS 73P-15 and -16); *in* Summary of Investigations 1985, Sask. Geol. Surv., Misc. Rep. 85-4, p18-27.

__________ (1987): Bedrock geological mapping, Bing Lake area (part of NTS 73P-7 and -10); *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p18-27.

Turner, F.J. and Weiss, L.F. (1963): Structural Analysis of Metamorphic Tectonites; McGraw-Hill Book Co. Ltd., 1963.

Project 8705

Mineralized Core Collection[1]

A.J. Gracie

Gracie, A.J. (1988): Mineralized core colection; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

The Mineralized Core Collection has been previously described (Gracie, 1984, 1985, 1986, 1987) and an updated index to the collection was released in 1987 as a data file (Gracie et al., 1987). The index identifies the location of all core from drillholes by longitude and latitude and on 1:250,000 scale maps, and gives full particulars of each hole: company, mineral dispositions, exploration commodity, year, hole number, core size, hole bearing and inclination, length of sample, reference to other exploration data and storage location.

The mineralized core is housed in the Precambrian Geological Laboratory in La Ronge. Contributions to the Mineralized Core Collection totalled some 1952 m in 1988 (Table 1) and were made up of cores from mineral properties drill-tested for gold (50 percent), base metals (33 percent) and uranium (17 percent). The mineralized core collection is augmented by an extensive collection of rock samples from mineral properties in northern Saskatchewan.

Table 1 – Mineralized Core Acquistions (September 1, 1987 to August 31, 1988)

Company or Joint Venture Operator	*(Commodity)*	*NTS Area Area*	*No. of Holes*	*Core Size*	*Property/Deposit Location by Lake*	*Length (m)*
Agip Canada Ltd.	(U)	74H-7	3	BQ	MPP 1000 (Zone S), Way Lake	56.9
Cameco	(U)	74F-11	1	BQ	CBS 8808, Derkson Lake	99.8
	(Au)	74A-1	1	NQ	Q 4447 (Jojay zone)	89.1
	(Au)	63L-9	1	NQ	ML 5274, Baby Gull Island	134.6
	(Au)	73P-7	1	NQ	ML 5428 (Pap Grid), Preview Lake	192.6
Claude Resources Inc.	(Au)	63M-12	2	NQ	ML 4784 (Seabee Decline), Laonil Lake	106.9
Corona Corp.	(Au)	74A-1	6	NQ	Jolu Mine (Rod zone)	449.3
Eldor Resources Ltd.	(U)	74O-6	3 plus 3 incomplete	BQ BQ	I.R. 228, Fraser Point, Fond-du-Lac	153.9 50.3
Hudson Bay Exploration and Development Ltd.						278.3
	(Cu, Zn, Ag, Au)	63K-13		BQ	Q 1282, Callinan Option, Main Mine area	
	(Cu, Zn, Pb, Ag)	63L-16	1	BQ	ML 5187, Fon claims, Matheson Lake	303.3
Ora Resources Inc.	(Au)	73P-6	1	NQ	CBS 6651, Waden Bay	36.8

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[1] Project funded under the Saskatchewan component of the Canada – Saskatchewan Subsidiary Agreement on Mineral Development 1984 – 89.

Table 2 - Paleozoic, Athabasca Group and Martin Group Core Shipped to the Subsurface Geological Laboratory, Regina (September 1, 1987 to August 31, 1988)

Company or Joint Venture Operator	*NTS Area Area*	*No. of Holes*	*Core Size*	*Property/Deposit Location by Lake*	*Length (m)*
Cameco	74N-7	1	HQ	CBS 5519 (Athabasca Group), Johnston Island	153
	74N-9	1	BQ	CBS 5638 (Martin Group), "Contact" Lake, Cutler Lake area	403.8
Cominco Ltd.	63L-1	2	BQ	CBS 7915-23 (Paleozoic), Berland Property	212.4
	63E-14	2	BQ	MPP 1144 (Paleozoic), Squaw Rapids	293.4
Uranerz Exploration and Mining Ltd.	74H-14	1	NQ	CBS 8928 (Athabasca Group), Reed Lake	771

Important stratigraphic cores are housed in the Subsurface Geological Laboratory in Regina. Contributions to this "Northern Stratigraphic Core Collection" totalled some 1834 m in 1988 (Table 2), comprising cores from Paleozoic, Athabasca Group and Martin Group rocks.

1. References

Gracie, A.J. (1984): Mineralized core collection; *in* Summary of Investigations 1984, Sask. Geol. Surv., Misc. Rep. 84-4, p127-128.

Gracie, A.J. (1985): Mineralized core collection; *in* Summary of Investigations 1985, Sask. Geol. Surv., Misc. Rep. 85-4, p82.

Gracie, A.J. (1986): Mineralized core collection; *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep. 86-4, p121-122.

Gracie, A.J. (1987): Mineralized core collection; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p80-81.

Gracie, A.J., Gray L.J. and Boissoneault G. (1987): Index to La Ronge core collection; Sask. Energy Mines, Data File 12, 162p.

Proterozoic Rocks of East-Central Saskatchewan: Geochemistry, Structure and Mineralization Controls[1]

G.R. Parslow[2] *and J.W. Gaskarth*[3]

Parslow, G.R. and Gaskarth, J.W. (1988): Proterozoic rocks of east-central Saskatchewan: geochemistry, structure and mineralization controls; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

The region considered in this paper is outlined on Figure 1. Figure 2 shows the major structural trends in the study area in more detail. A convenient subdivsion is to consider the southern portion of the area, part of the Flin Flon Domain, as predominantly Amisk volcanic rocks of low grade and dated at about 1.8 Ga (Bell et al., 1975; Mukherjee et al., 1971; Watters and Armstrong, 1985), and the northern portion, part of the Kisseynew Domain, as higher grade clastic rocks of uncertain age, considered coeval with the Amisk Group by many authors (review by Moore, 1977; Bailes, 1980; Ashton et al., 1987). The boundary zone between the two areas is marked by a rapid change of metamorphic grade and extreme tectonism; thus, it is a possibly major shear zone (Parslow and Gaskarth, 1985; Gaskarth and Parslow, 1987) which we have referred to as the Pargas Shear Zone. This east-trending boundary

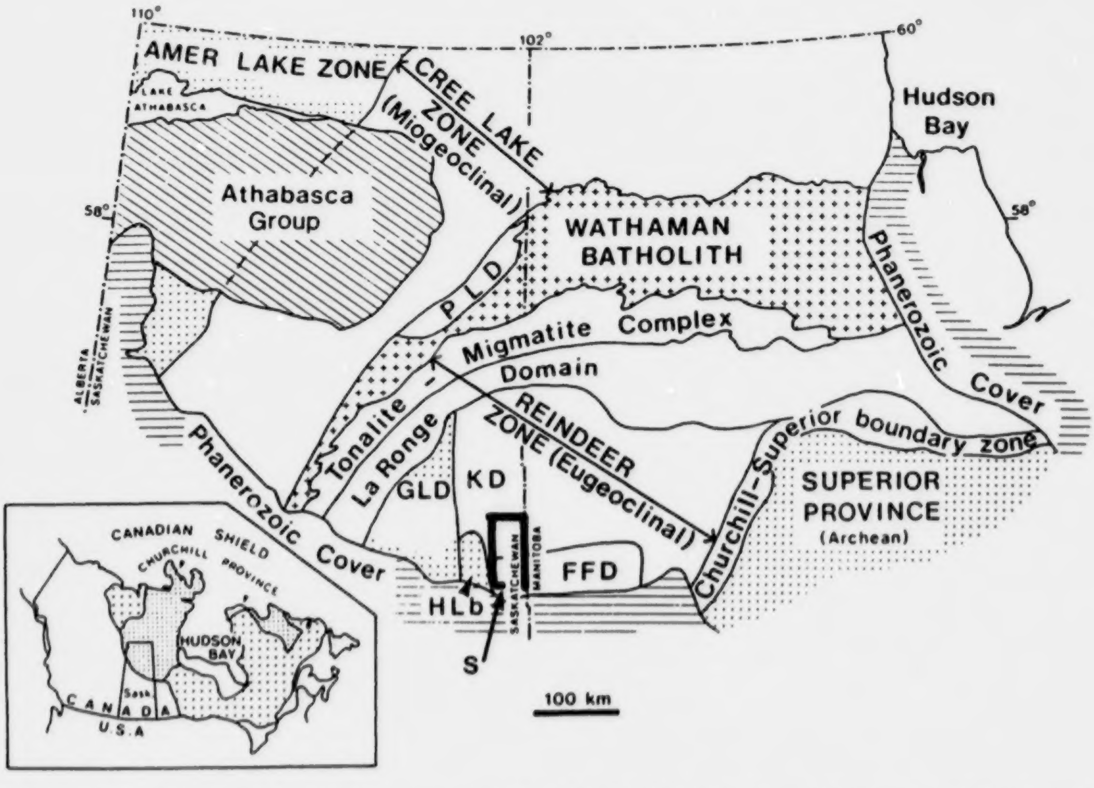
110°
102°
60°
58°
58°
AMER LAKE ZONE
LAKE ATHABASCA
CREE LAKE ZONE (Miogeoclinal)
Hudson Bay
Athabasca Group
WATHAMAN BATHOLITH
PLD
Phanerozoic Cover
ALBERTA
SASKATCHEWAN
Migmatite Complex
Domain
Tonalite
La Ronge
REINDEER ZONE (Eugeoclinal)
Superior boundary zone
Churchill
SUPERIOR PROVINCE
(Archean)
GLD
KD
Phanerozoic Cover
SASKATCHEWAN
MANITOBA
FFD
HLb
S
100 km
CANADIAN SHIELD
CHURCHILL PROVINCE
HUDSON BAY
Sask.
CANADA
U.S.A

Figure 1 - Major lithostructural domains of the eastern part of the Churchill Province in Canada (after Lewry and Sibbald, 1980; Fumerton et al., 1984; Stauffer, 1984). PLD, Peter Lake Domain; GLD, Glennie Lake Domain; HLb, Hanson Lake block; KD, Kisseynew Domain; FFD, Flin Flon Domain; S, study area.

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(1) Modified text of a paper presented by G.R. Parslow at IGCP Project 217 Meeting "Geochemistry and Mineralization of Proterozoic Mobile Belts", held in Tianjin, People's Republic of China, September, 1988

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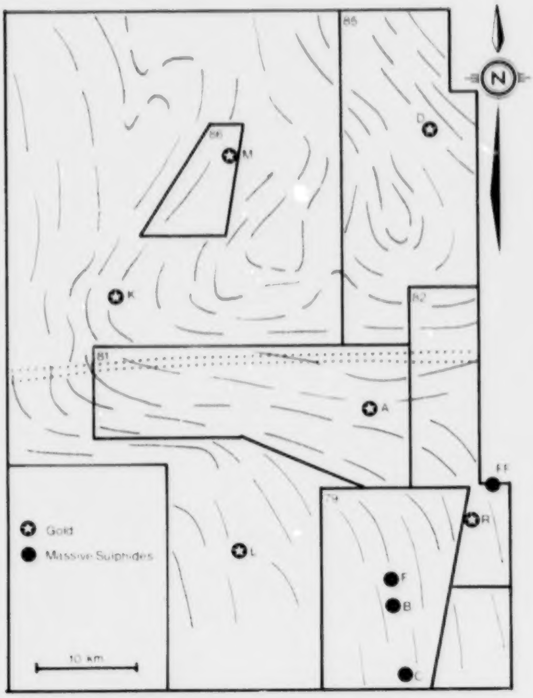

Figure 2 – Structural trends and selected mineralized zones in east-central Saskatchewan. Study areas are outlined and identified by a number in the top left hand corner: 79, East Amisk Lake area; 81, Annabel Lake area; 82; Hamell Lake area; 85, Mari Lake (Kisseynew) area; 86, Wildnest Lake area. Massive sulphide deposits: FF, Flin Flon; F, Flexar; B, Birch Island; C, Coronation. Gold occurrences: L, Laurel Lake; A, Annabel Lake; K, Kibzey Lake; D, Dolly showing; M, Manson Bay. The dashed lines running E-W across the centre of the figure define the zone of rapid metamorphic grade change from lower greenschist facies in the south to upper amphibolite to lower granulite facies in the north.

line can be traced westwards on regional geological maps for more than 200 km.

Ayres et al. (1981), Byers and Dahlstrom (1954), Byers et al. (1965), Coombe (1979), Froese (1969) and Stauffer et al. (1975) have all concluded that rocks in the Flin Flon Domain represent greenschist facies equivalents of volcanic rocks involved in at least two important periods of deformation. In general, the rocks are black and have lost their original mineralogy, but various palimpsest fabrics, such as pillows, phenocrysts, amygdales and lapilli, remain. Way-up criteria, which are rare, indicate younger rocks towards the south and west. Tectonism has rendered most contacts subconcordant so that the distinction between intrusive and extrusive rocks is largely predicated upon grain size, except in the Hamell Lake area (82 on Figure 2) where it is possible, due to smelter pollution, to positively identify mafic dykes and late subvolcanic intrusions on barren acid-leached outcrops. The volcanic sequence comprises predominantly subaqueous basaltic rocks, particularly in the East Amisk area (79 on Figure 2), with more pyroclastic units towards the north, particularly in the Annabel Lake and Hamell Lake areas (81 and 82 on Figure 2). When exposures are good, many dykes, late gabbros and felsic intrusives can be identified. Although the last-mentioned pre- to syntectonic "granites" have been omitted from Figure 2 for clarity, they account for some 30 percent of the succession. The East Amisk area contains numerous gabbroic and ultrabasic bodies.

The volcanic rocks are unconformably overlain by the molasse-type Missi Group which is cut by the late "Boundary Intrusions". Missi-like units are also found within the volcanic sequence; thus, even though the unconformity is often visually impressive, the evidence suggests that there is no major temporal hiatus between the volcanics and the molasse.

The majority of faults trend approximately north-south except in the Annabel Lake region. In this area, just south of the Pargas Shear Zone (Figure 2), clasts in volcaniclastic rocks exhibit moderate flattening and elongation, and are locally reduced to mylonites.

North of the Pargas Shear Zone, the Kisseynew Gneisses form a sequence of biotite and hornblende gneisses with thin units of amphibolite and hornblende diorite forming marker horizons that define the main structures (Byers and Dahlstrom, 1954; Cheesman, 1956; Johnson, 1966; Macdonald, 1975; Pyke, 1961, 1965). The rocks are essentially pink, the dominant foliation is flat lying, and the grade is upper amphibolite to granulite facies. Relict fabrics are locally preserved in the more mafic units; in particular, at the Dolly gold showing (D on Figure 2), a feldspar-phyric basalt is recognizable. Such evidence indicates that at least some of the Kisseynew hornblende-rich rocks are igneous (and possibly volcanic) in origin. On the other hand, the gneisses are in places graphite-bearing and associated with calc-silicate units which are apparently derived from a sedimentary protolith. However, a felsic volcanic component cannot be ruled out in at least some cases. Delineation of a lower greywacke sequence with associated volcanic rocks, the Nokomis Group, and an upper arkosic sequence with associated volcanic rocks, the Sherridon Group, as is found in the type area of the Kisseynew in Manitoba (Robertson, 1953), has not been confirmed in the Saskatchewan portion of the Kisseynew Domain by Ashton et al. (1986, 1987). Although presently interpreted as a coeval interarc basin bounded to the northwest by the La Ronge–Lynn Lake arc and to the south by the Flin Flon–Snow Lake arc, the exact temporal relationships of the Kisseynew Domain with the adjacent Proterozoic volcanic rocks are unknown.

1. Mineral Deposits

Numerous mineral showings have been documented in the Flin Flon volcanics and, to a lesser extent, in the Kisseynew Domain in Saskatchewan (e.g., McDougall et al., 1982). Many are small pockets of massive sulphides containing Cu and Zn or late quartz veins containing gold. Some of the larger deposits, chosen to illustrate

Table 1 – Average Analyses of Flow and Fragmental Volcanics, East Amisk Area (Standard Deviation in Parentheses)

	BAS	*BAN*	*AND*	*DAC*	*RHY*
SiO_2	49.07(2.75)	54.06(0.76)	58.03(1.43)	64.45(2.02)	72.20(3.02)
TiO_2	1.53(0.67)	1.22(0.75)	1.13(0.77)	0.59(0.52)	0.31(0.11)
Al_2O_3	15.00(2.12)	15.06(1.39)	14.88(1.87)	15.82(1.05)	12.93(3.01)
Fe_2O_3	3.68(1.51)	3.48(1.58)	2.85(1.52)	1.94(0.96)	1.55(1.54)
MnO	0.18(0.07)	0.17(0.06)	0.15(0.05)	0.10(0.06)	0.06(0.04)
FeO	8.53(1.94)	8.14(2.46)	7.16(2.35)	4.72(2.64)	2.76(1.21)
MgO	8.46(4.25)	6.27(1.94)	4.96(1.77)	2.73(1.40)	2.15(1.38)
CaO	10.29(3.26)	7.68(2.39)	6.29(2.66)	4.76(1.43)	3.20(1.40)
Na_2O	2.54(0.99)	3.14(1.11)	3.18(1.31)	3.27(1.53)	3.40(1.53)
K_2O	0.56(0.67)	0.63(0.86)	1.17(1.01)	1.51(1.14)	1.32(1.28)
P_2O_5	0.15(0.11)	0.14(0.07)	0.19(0.16)	0.11(0.05)	0.12(0.11)
H_2O^-	0.15(0.14)	0.14(0.09)	0.15(0.12)	0.13(0.08)	0.12(0.11)
LOI	4.10(3.90)	3.14(2.18)	4.17(3.49)	2.76(2.19)	2.58(1.68)
Ba	142 (226)	153 (172)	308 (360)	370 (405)	315 (474)
Cr	243 (713)	123 (246)	90 (135)	43 (72)	67 (212)
Cu	83 (60)	142 (524)	69 (80)	64 (45)	58 (101)
Nb	8 (5)	6 (4)	7 (6)	5 (3)	6 (5)
Ni	91 (194)	48 (47)	39 (48)	21 (20)	28 (79)
Pb	4 (14)	3 (2)	4 (4)	4 (4)	4 (3)
Rb	11 (12)	10 (12)	20 (22)	24 (20)	17 (17)
Sr	230 (126)	173 (140)	200 (206)	204 (181)	174 (194)
Th	2 (1)	3 (2)	3 (3)	3 (2)	4 (2)
U	2 (1)	2 (1)	2 (2)	2 (1)	2 (2)
V	323 (145)	348 (140)	229 (141)	182 (144)	70 (50)
Y	27 (9)	27 (11)	30 (19)	18 (13)	31 (47)
Zn	100 (87)	90 (34)	79 (26)	64 (35)	38 (31)
Zr	101 (48)	87 (60)	118 (101)	83 (50)	85 (57)
n	356	60	43	10	26

Oxides in weight percent on an anhydrous basis, except for H_2O^- and LOI which are in weight percent; trace elements in ppm.

BAS	Basalt
BAN	Basaltic andesite
AND	Andesite
DAC	Dacite
RHY	Rhyolite (based on SiO_2 classification described in text)
n	number of samples in file

the variation in mineralization style, are located on Figure 2.

The Flin Flon deposit (FF on Figure 2), discovered in 1914, is a classical massive sulphide, occurring in a thin sequence of felsic flow rocks and mafic volcaniclastic rocks bounded above and below by thick sequences of basaltic pillow lavas and flow breccias. An extensive alteration pipe, present below the deposit (Byers et al., 1965; Sangster, 1972), is illustrated by depletion of SiO_2, K_2O and Na_2O and enrichment in MgO, CaO, CO_2 and H_2O (Koo & Mossman, 1975).

The Flexar, Birch Island and Coronation deposits (F, B, and C on Figure 2) are more typical of the smaller massive sulphide occurence that are found in east-central Saskatchewan and west-central Manitoba. These vary from 1 to 5 million tonnes and have similar Cu and Zn grades to the main deposit. Host rock, footwall and hanging wall lithologies are similar, although alteration effects are usually much less obvious and are less pervasive. Deposits in this size range have been mined over the years to feed the Flin Flon smelter.

No massive sulphide deposits worthy of exploitation have been found to date in the Kisseynew Domain in Saskatchewan.

Historically, gold occurrences in the volcanics have been viewed as fracture-controlled carbonate-quartz-sulphide zones associated with both the volcanics and later felsic intrusives (Pearson, 1987), such as in the area around the Rio deposit (R on Figure 2). Another example of shear-controlled enrichment of gold is the Annabel Lake showing (A on Figure 2); here the gold lies within the sheared volcaniclastic rocks and is accompanied by barren pyrite and pyrrhotite. The recently discovered Laurel Lake gold-sulphide zone (L on Figure 2) is associated with a massive porphyry and related pyroclastic rocks; disseminated mineralization includes tetrahedrite, sphalerite and galena in a synvolcanic epithermal environment (Walker and McDougall, 1987).

Examples of showings in the Kisseynew are the Dolly, Manson Bay and Kibzey Lake occurrences (D, M and K on Figure 2). There is normally evidence of shearing close to or within these deposits. Commonly, sulphides are also present. Although grades in places exceed 20 g/t Au, tonnages have never proven large enough to warrant exploitation. The gold is not normally visible and is dispersed through all rock types in the immediate vicinity.

2. Present Study and Objectives

During the period 1978 – 88, Saskatchewan Energy and Mines sponsored a series of sampling and analytical projects with one of the authors (GRP). The prime objective was to attempt a better definition and understanding of the Amisk volcanics and the Kisseynew Gneisses through geochemistry. This paper represents the first regional study of the geochemistry of these Proterozoic rocks.

Sampling was undertaken between 1979 and 1986 in the areas shown in Figure 2. The nearly 3000 samples that were collected and analyzed are distributed as follows: East Amisk in 1979 (n = 821), Annabel Lake in 1981 (n = 1087), Hamell Lake in 1982 (n = 499), Mari Lake in 1985 (n = 290), Wildnest Lake in 1986 (n = 112). With the exception of the Wildnest Lake area, major felsic intrusives and gneisses of possible sedimentary origin were not sampled systematically. It is considered, however, that volcanic and associated subvolcanic intrusives or their presumed high-grade

Table 2 – Average Analyses of Flow and Fragmental Volcanics, Annabel Lake Area (Standard Deviation in Parentheses)

	BAS	*BAN*	*AND*	*DAC*	*RHY*
SiO_2	49.17(2.42)	54.33(0.83)	58.94(1.78)	64.62(1.71)	71.23(2.32)
TiO_2	0.71(0.42)	0.64(0.22)	0.61(0.25)	0.49(0.12)	0.30(0.11)
Al_2O_3	16.37(1.98)	15.42(1.32)	15.32(1.63)	15.50(1.47)	13.88(1.62)
Fe_2O_3	1.73(1.25)	1.81(1.37)	1.44(1.00)	1.00(0.62)	1.09(0.87)
MnO	0.19(0.04)	0.20(0.04)	0.16(0.05)	0.11(0.06)	0.09(0.06)
FeO(c)	9.54(2.68)	9.52(2.13)	7.98(2.39)	5.19(2.36)	3.37(1.54)
MgO	5.97(1.62)	4.51(1.27)	3.41(1.03)	2.09(0.83)	0.88(0.39)
CaO	13.42(3.35)	9.93(1.65)	7.70(2.12)	5.17(1.52)	3.77(1.25)
Na_2O	2.04(0.75)	2.61(0.94)	2.83(1.07)	3.76(1.29)	3.57(1.34)
K_2O	0.65(0.41)	0.81(0.54)	1.34(0.99)	1.83(1.11)	1.66(0.72)
P_2O_5	0.22(0.24)	0.23(0.07)	0.27(0.09)	0.26(0.07)	0.15(0.05)
H_2O^-	0.12(0.13)	0.11(0.14)	0.10(0.11)	0.11(0.12)	0.09(0.09)
LOI	1.98(1.99)	0.94(0.93)	1.22(1.01)	1.02(0.66)	0.86(0.70)
Ba	163 (146)	189 (150)	359 (264)	668 (442)	461 (200)
Cr	133 (151)	88 (167)	56 (77)	42 (62)	9 (14)
Cu	90 (63)	74 (59)	73 (58)	42 (48)	25 (39)
Nb	5 (2)	5 (2)	7 (4)	8 (2)	7 (3)
Ni	57 (37)	29 (24)	22 (16)	15 (12)	7 (8)
Pb	6 (5)	8 (28)	7 (3)	10 (6)	8 (4)
Rb	10 (12)	12 (14)	24 (21)	33 (20)	28 (12)
Sr	240 (113)	233 (115)	354 (221)	583 (374)	270 (154)
Th	1 (1)	2 (1)	3 (2)	3 (2)	3 (4)
U	1 (1)	1 (1)	2 (1)	2 (2)	2 (1)
V	230 (89)	227 (87)	143 (74)	69 (39)	27 (17)
Y	20 (8)	24 (7)	25 (7)	24 (13)	29 (16)
Zn	93 (34)	100 (27)	96 (25)	84 (27)	76 (42)
Zr	53 (29)	60 (31)	90 (46)	120 (36)	114 (46)
n	471	101	128	60	74

Abbreviations as in Table 1

equivalents are represented in a consistent manner in the sample population.

The samples were crushed and then analyzed for major elements, excluding Na_2O and K_2O, by ICP and for trace elements by XRF. The alkalis were determined by AAS. Ferrous iron was determined only on the East Amisk suite; in all other cases $FeO(c) = 0.9 \times$ total Fe_2O_3 and Fe_2O_3 = total $Fe_2O_3 - FeO(c)$. A limited number of East Amisk samples were analyzed for their REE content by NAA. Complete analytical data files for all samples, as well as an assessment of the precision and accuracy of the data, can be found in Parslow (1986) and Parslow and Gaskarth (1984, 1985, 1986, 1987).

All computations and manipulations of data were carried out on anhydrous files; that is, the analyses were resummed to 100 percent minus the H_2O^- and LOI. Average analyses of various chemically defined volcanic rock types from the different areas are given in Tables 1 to 4. To simplify many of the graphs, only averages of groups of analyses are plotted.

3. Interpretation of the Data

The following text describes the preliminary interpretation of this large data base.

Tables 1 to 4 show that the effects of volcanic-related hydrothermal systems, halmyrolysis and later metamorphism are manifested as rather large standard deviations for more mobile elements, such as Ca, Ba and Sr, in the southern (low grade) volcanics and a more general increase in standard deviations for the northern (high-grade) suspected volcanics. Even so, plots of compatible and incompatible element pairs (not shown) give moderate to good positive and negative correlations, suggesting that igneous liquid lines of descent have been in essence preserved.

For the most part, frequency distributions of the various elements in chemically defined rock groups are essentially unimodal, and mean values (i.e., frequency peaks) coincident from area to area. One clear exception to this is the TiO_2 distribution in the East Amisk basalts. The data are shown in Figure 3 in comparison to the Annabel Lake basalts, which are typical of the basalts from elsewhere. The Annabel data are positively skewed with an average TiO_2 content of about 0.5 percent. While the East Amisk data contain only a small peak at this value, the main peak is at about 1.5 percent TiO_2. Dividing the East Amisk basalts into low, medium, and high TiO_2 groups (<1 percent, 1 to 2 percent and >2 percent) yields the statistics shown in Table 5, which indicate that sympathetic correlations between TiO_2 and, in particular, Nb, Y, and Zr (i.e., rocks low in TiO_2 are also low in Nb, Y, and Zr). This

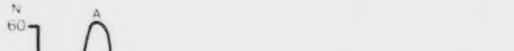

Figure 3 – Frequency (N) histogram of TiO_2 (percent) in "chemical" basalts (i.e., SiO_2<53 percent) from the Annabel Lake (A) and East Amisk Lake (EA) areas.

Table 3 – Average Analyses of Flow and Fragmental Volcanics, Hamell Lake Area (Standard Deviation in Parentheses)

	BAS	*BAN*	*AND*	*DAC*	*RHY*
SiO_2	50.37(1.78)	54.10(0.85)	57.85(1.54)	65.64(1.60)	75.11(3.62)
TiO_2	0.59(0.28)	0.61(0.20)	0.60(0.13)	0.47(0.10)	0.20(0.11)
Al_2O_3	16.01(1.66)	14.87(0.91)	14.65(1.23)	14.87(1.48)	12.31(1.33)
Fe_2O_3	1.31(0.87)	1.42(1.16)	1.18(0.22)	0.60(0.20)	0.35(0.17)
MnO	0.21(0.03)	0.22(0.04)	0.21(0.04)	0.12(0.09)	0.06(0.03)
FeO(c)	11.05(2.04)	11.48(2.06)	10.60(1.99)	5.40(1.84)	3.14(1.50)
MgO	5.91(1.69)	4.54(1.04)	3.34(0.90)	1.90(0.68)	0.75(0.44)
CaO	11.60(2.02)	9.26(1.60)	7.24(1.45)	5.39(1.86)	2.53(1.21)
Na_2O	2.19(0.75)	2.61(0.78)	3.20(0.96)	3.63(1.18)	3.68(1.26)
K_2O	0.54(0.38)	0.66(0.51)	0.86(0.62)	1.73(1.00)	1.73(0.79)
P_2O_5	0.22(0.10)	0.24(0.09)	0.28(0.09)	0.26(0.10)	0.13(0.08)
H_2O^-	0.08(0.06)	0.08(0.06)	0.08(0.06)	0.10(0.06)	0.06(0.04)
LOI	1.83(1.39)	1.45(0.82)	1.62(1.35)	1.69(1.31)	1.15(0.81)
Ba	170 (105)	203 (133)	264 (224)	510 (385)	456 (284)
Cr	99 (120)	31 (78)	24 (70)	31 (45)	4 (5)
Cu	87 (54)	89 (59)	75 (60)	42 (42)	31 (51)
Nb	3 (1)	3 (3)	3 (1)	7 (2)	6 (1)
Ni	47 (47)	19 (22)	11 (14)	11 (13)	3 (2)
Pb	12 (43)	10 (29)	5 (3)	8 (6)	6 (6)
Rb	11 (10)	12 (12)	15 (14)	29 (15)	25 (13)
Sr	211 (157)	197 (111)	203 (111)	371 (282)	121 (74)
Th	2 (1)	2 (1)	3 (1)	4 (3)	6 (2)
U	1 (1)	1 (1)	1 (1)	3 (2)	2 (1)
V	265 (188)	268 (192)	162 (103)	70 (23)	27 (14)
Y	20 (7)	23 (6)	27 (8)	18 (8)	49 (19)
Zn	99 (25)	103 (18)	101 (24)	65 (30)	60 (32)
Zr	41 (22)	47 (27)	56 (20)	104 (38)	141 (29)
n	129	81	60	13	45

Abbreviations as in Table 1

suggests that more than one magmatic evolutionary trend is present because of the wide range in TiO_2, Nb, Y, and Zr values in these basalts. It is concluded that the East Amisk basalts are different from the Annabel, Hamell and, to an extent, the Kisseynew basalts, although the last-mentioned rocks may have suffered element migration due to high-grade metamorphism.

a) Frequency of Occurrence of Rock Types

Watters and Pearce (1987) documented the La Ronge volcanic belt of Saskatchewan (Figure 1) as a predominantly calc-alkaline oceanic island arc sequence composed of 50 percent basalt, 35 percent andesite and 15 percent dacite and rhyolite, and cut by later intrusives that account for some 30 to 40 percent of the outcrop in the region. Their observations closely match the observations for many recent island arc sequences (Jakes and White, 1971).

In the present study, the distribution of rock types is based on geochemical data alone, and the field identification of rock types has not been considered. The data are shown in Figure 4 in histogram form using a simple SiO_2 discriminant of <53 percent for basalt, 53 to 55.9 percent for basaltic andesite, 56 to 61.9 percent for andesite, 62 to 67.9 percent for dacite and ≥68 percent for rhyolite. In general, the dominant rocks at Flin Flon are more basic than those of the La Ronge Domain. In particular, the East Amisk (EA) sequence is composed of 80+ percent basaltic rocks (BAS + BAN) and only 8 percent andesites (AND); such a distribution is atypical of island arcs. The Annabel (A) and Hamell (H) Lakes data fall closer to an arc distribution, with 70 percent basaltic rocks and 20 percent andesites. Also the ratio of fragmental volcanics (upper portion of histogram bar) to flow volcanics (lower portion) is quite small for a true island arc sequence; for example in the La Ronge belt, the ratio averages 1.0 and rises in places to 4.0, while for the present study the ratio rarely approaches 0.33. The Kisseynew Domain (K) hornblende-bearing rocks are shown for completeness, although their origin is uncertain. They do, however, show a distribution of "chemical" rock types similar to the volcanics from the southern part of the area.

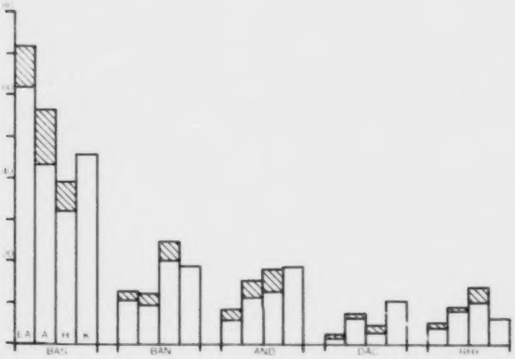

Figure 4 – Percentage frequency histogram of chemically defined volcanics, both flow and fragmental, from the East Amisk (EA), Annabel (A), Hamell (H) and Kisseynew (K) areas. The chemical divisions are based on SiO_2 as follows: basalt (BAS) <53 percent, basaltic andesite (BAN) 53 to 55.99 percent, andesite (AND) 56 to 61.99 percent, dacite (DAC) 62 to 67.99 percent, and rhyolite (RHY) >67.99 percent. The order of histogram bars in each group is, from left to right, EA, A, H, K. With the exception of the Kisseynew data, the lower portion of a given histogram bar represents percentage flow volcanics and the upper portion represents percentage fragmental volcanics.

Table 4 - Average Analyses of Flow and Fragmental Volcanics, Kisseynew Area (Standard Deviation in Parentheses)

	BAS	*BAN*	*AND*	*DAC*	*RHY*
SiO_2	50.22(2.11)	53.99(0.72)	57.88(1.66)	65.05(2.12)	71.74(2.27)
TiO_2	0.92(0.46)	0.91(0.40)	0.68(0.27)	0.63(0.21)	0.57(0.09)
Al_2O_3	16.81(3.14)	17.16(1.78)	14.92(3.55)	14.36(2.28)	13.06(1.30)
Fe_2O_3	1.14(0.28)	1.01(0.21)	1.11(0.57)	0.81(0.31)	0.53(0.07)
MnO	0.19(0.09)	0.16(0.04)	0.21(0.22)	0.12(0.06)	0.06(0.02)
FeO(c)	9.26(2.30)	8.21(1.71)	8.96(4.66)	6.58(2.54)	4.32(0.55)
MgO	7.13(3.28)	4.65(1.23)	4.28(2.19)	2.73(2.01)	1.60(0.49)
CaO	11.18(1.65)	9.16(1.36)	8.20(2.29)	5.05(1.79)	2.92(0.47)
Na_2O	2.20(0.77)	3.03(0.84)	2.29(1.20)	2.67(0.93)	2.71(0.32)
K_2O	0.70(0.61)	1.41(0.82)	1.19(0.91)	1.75(0.71)	2.27(0.39)
P_2O_5	0.25(0.09)	0.28(0.09)	0.27(0.11)	0.26(0.06)	0.21(0.02)
H_2O^-	0.05(0.04)	0.07(0.04)	0.05(0.03)	0.07(0.04)	0.05(0.03)
LOI	1.01(0.64)	1.04(0.48)	0.73(0.44)	1.07(0.86)	0.63(0.23)
Ba	99 (132)	316 (250)	1002 (3898)	346 (177)	484 (94)
Cr	320 (466)	107 (223)	148 (337)	120 (244)	114 (64)
Cu	79 (142)	49 (44)	53 (61)	28 (15)	7 (7)
Nb	7 (3)	8 (3)	7 (3)	9 (2)	9 (1)
Ni	130 (202)	36 (48)	63 (162)	24 (22)	33 (15)
Pb	7 (7)	11 (8)	7 (3)	9 (3)	10 (2)
Rb	11 (16)	28 (23)	24 (25)	37 (19)	52 (12)
Sr	217 (87)	306 (248)	229 (144)	251 (157)	339 (99)
Th	2 (1)	3 (2)	3 (2)	3 (2)	7 (1)
U	1 (1)	2 (1)	2 (1)	2 (1)	2 (1)
V	234 (106)	215 (108)	184 (100)	99 (49)	102 (47)
Y	23 (9)	27 (8)	25 (7)	30 (14)	21 (5)
Zn	91 (78)	95 (37)	80 (17)	77 (22)	53 (19)
Zr	78 (42)	108 (43)	145 (236)	128 (50)	151 (43)
Au	10 (32)	2 (4)	3 (4)	3 (5)	4 (6)
n	60	25	24	13	8

Abbreviations as in Table 1

b) Chemical Character of the Volcanic Data

AFM (Irvine and Baragar, 1971) and Y+Zr - Cr - $TiO_2 \times 100$ (Davies et al., 1979) plots of the geochemical data (Figure 5) indicate a basic sequence that is tholeiitic, with only the relatively rare dacites and rhyolites exhibiting calc-alkaline affinities. These trends are expected in the lower level of an arc sequence or the early stages of arc development where "passive" oceanic material is still a significant component of the volcanic sequence. Kisseynew Domain rocks in this region show the same trend, although with a significant enrichment of Cr, suggesting that they may have been coeval with the Flin Flon volcanics. Data for the late ultrabasic, basic and acid Boundary Intrusions (so called because of their proximity to the Saskatchewan-Manitoba boundary) exhibit, however, a convincing calc-alkaline trend (Figure 5) and provide a further indication that the volcanics evolved from an early basic-intermediate tholeiitic sequence into an acidic calc-alkaline sequence accompanied by later calc-alkaline plutonism of varied composition.

c) Environment of Formation of the Volcanic Rocks

Numerous discriminant diagrams have been proposed over the last fifteen years to classify volcanic rocks, mainly basalts, in terms of plate tectonic processes. Although only four are considered in detail in this paper, the observations and conclusions are applicable to most other diagrams. Additional plots of selected basalts, dykes, gabbros and ultrabasic rocks can be found in Gaskarth and Parslow (1987).

The log Ti - log Zr diagram (Pearce, 1982) shown in Figure 6 discriminates arc lavas from within-plate lavas with a superimposed MORB field. This diagram, moreover, has the advantage that both basic rocks and their more evolved fractionation products can be displayed. Average values for the chemically defined rock types of the Annabel Lake, Hamell Lake and Kisseynew sequences define a clear arc lava association with a typical negative correlation between Ti and Zr. The East Amisk trend is different, however, essentially decreasing Ti for a constant Zr. The two points for basalts and basaltic andesites represent over 80 percent of the data and lie well within the MORB field.

When broken down, the East Amisk data are more complex. It was noted above that the East Amisk basalts could be subdivided into a dominant 1.5 percent TiO_2 group, a much smaller 0.5 percent TiO_2 group, and possibly a very minor 2.5 percent TiO_2 group. A plot of these subgroups on a log Ti - log Zr diagram (Figure 7) illustrates their distribution. The low-Ti group is quite discrete from the other two, and has a typical arc chemistry similar to the Annabel, Hamell and Kisseynew data in Figure 6. The dominant 1.5 percent TiO_2 group sits almost centrally in the MORB field and straddles the arc - within-plate boundary. The small high-Ti group, although still within the MORB field, lies in the within-plate field. These plots corroborate earlier suggestions (Figure 3 and Table 5) that the East Amisk area is unique because there is evidence of more than one evolutionary trend. Figure 7 suggests that arc, MORB and even within-plate volcanism may be represented.

A further confirmation of tectonic setting derives from the log Cr - log Y diagram for basaltic rocks (Pearce, 1980, 1982) shown in Figure 8. The average basalts and basaltic andesites all fall effectively in the arc basalt field. However, if the East Amisk basalt data are split into the three subgroups (L, M, H), as previously (Figures 3 and 7, and Table 5), then the low-Ti group is clearly arc related while the other two can be interpreted as MORB or within-plate types.

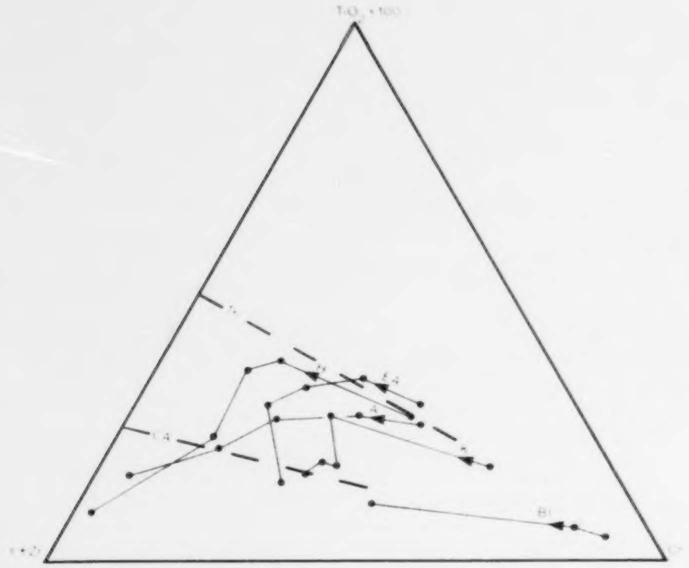

Figure 5 - Ternary diagram of (Y+Zr)-Cr-(TiO₂ × 100) which discriminates between tholeiitic (Th) and calc-alkaline (CA) trends in volcanic and associated rocks (after Davies et al., 1979). Abbreviations for the various areas as in Figure 4 plus BI, Boundary intrusions. The dots represent average values for BAS, BAN, AND, DAC and RHY from right to left, except for BI where the dots are for ultrabasic, basic and acid intrusions from right to left.

Geochemical signature diagrams, where many elements are ordered into a sequence of low to high field strength (effectively a mobile to immobile sequence) and normalized to an average MORB composition (Figures 9 and 10), provide another means of attempting to characterize the environment of formation of a volcanic sequence. Figure 9 illustrates data for the various subgroups of East Amisk basalts and Figure 10 shows data for the other areas. For interpretative purposes the following general observations apply:

1) MORB-type basalts should plot very close to the line *rock/MORB = 1*, although many MORB basalts (particularly the more alkaline sequences) show an enrichment of the elements Sr through Ta;

2) Within-plate lavas exhibit a general enrichment of all elements (i.e., they plot above *rock/MORB = 1*);

3) Arc-related basalts show an enrichment of the elements Sr through Ta and a depletion of the elements Nb through Cr (typical trends of various Phanerozoic rock suites can be found in Pearce (1982, 1983).

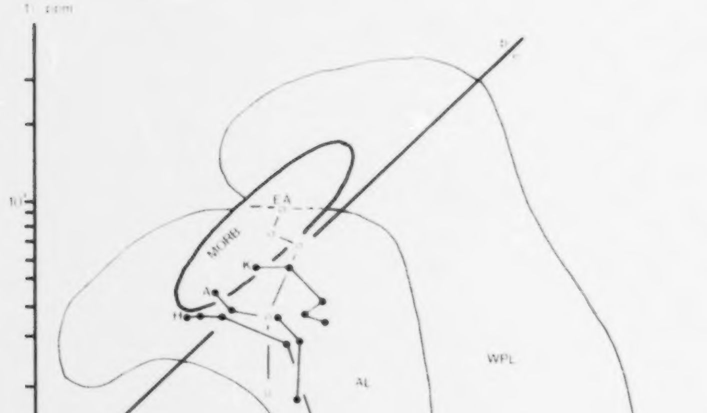

Figure 6 - Binary diagram of log Zr-log Ti (after Pearce, 1982) which discriminates mid-ocean ridge basalts (MORB), arc lavas (AL) and within-plate lavas (WPL). Rocks above the linear trend are basic (b) and those below more evolved (e). Abbreviations for trend lines as in Figure 4 and located next to the BAS average; the other dots or circles represent BAN, AND, DAC and RHY

In Figure 9, the three subgroups of East Amisk basaltic rocks suggest that the low-Ti group is arc related, the mid-Ti group is MORB or perhaps within-plate related, and the high-Ti group is within-plate in character. In Figure 10 the Annabel Lake, Hamell Lake and Kisseynew basaltic rocks show signatures very similar to those of the low-Ti East Amisk or arc-type rocks. The rather high and anomalous P values may reflect the fact that this element has the lowest precision of all the elements determined by ICP. The data in both Figures 9 and 10 should be treated with caution because in the former the plots are based upon averages of only three comprehensive analyses of each subgroup, while the data in the latter figure, other than those from East Amisk, represent large numbers of samples but without the key elements Th, Ta, Ce, Hf, Sm, Yb and Sc.

Most of the volcanic rocks in the areas therefore appear to be arc related, and arc-related volcanics are present in the East Amisk data; however, the oceanic or continental nature of the arc remains in question. An oceanic arc is favoured by the authors because 1) the volcanics are predominantly subaqueous, 2) acid volcanics and volcaniclastics are rare,

Table 5 – Average Analyses of Low-, Medium- and High-Ti Basalts, East Amisk Area (Standard Deviation in Parentheses)

	LTI(sd)	*MTI(sd)*	*HTI(sd)*
SiO_2	50.07(1.93)	49.23(1.86)	48.96(2.29)
TiO_2	0.49(0.24)	1.60(0.22)	2.38(0.26)
Al_2O_3	15.61(1.48)	15.00(1.28)	15.30(1.47)
Fe_2O_3	2.99(1.24)	3.68(1.28)	3.98(1.51)
MnO	0.16(0.06)	0.19(0.08)	0.19(0.08)
FeO	7.84(1.85)	8.67(1.58)	8.58(1.96)
MgO	9.72(2.84)	7.95(1.54)	6.87(1.25)
CaO	10.02(2.64)	10.51(2.19)	10.20(2.30)
Na_2O	2.43(0.95)	2.61(0.79)	2.81(1.29)
K_2O	0.55(0.62)	0.41(0.50)	0.55(0.48)
P_2O_5	0.12(0.13)	0.15(0.11)	0.18(0.08)
H_2O^-	0.15(0.11)	0.15(0.16)	0.16(0.12)
LOI	2.62(1.94)	3.72(2.67)	3.46(2.43)
Ba	164 (318)	114 (214)	163 (138)
Cu	85 (106)	82 (38)	76 (43)
Nb	3 (1)	7 (2)	13 (5)
Ni	95 (77)	68 (25)	61 (21)
Pb	6 (22)	3 (4)	3 (2)
Rb	10 (10)	8 (8)	10 (8)
Sr	150 (122)	247 (111)	289 (125)
Th	2 (1)	2 (1)	2 (1)
U	1 (1)	1 (1)	2 (2)
V	288 (233)	330 (109)	363 (129)
Y	15 (7)	28 (5)	36 (6)
Zn	65 (25)	98 (24)	110 (23)
Zr	35 (23)	101 (16)	161 (31)
n	70	210	76

and 3) with the exception of the Kisseynew area, the rare metasedimentary rocks are finely laminated shaly rocks containing Fe-rich layers. Based on the arc discriminant diagram of Pearce (1983) shown in Figure 11, the points for average basalts (note that EA is the average for East Amisk low-Ti basalts only) fall unquestionably in the oceanic field, except in the case of the Kisseynew rocks. The mid- and high-Ti basalts from the East Amisk area (m and h on Figure 11) plot well into the *continental* arc field, further proof that these rocks are not arc related.

d) Geochemical Controls on Mineralization

In a previous paper, Parslow (1987) demonstrated that the massive sulphide deposits of Flexar, Birch Island and Coronation in the East Amisk area were spatially associated with rocks low in Ti and Nb, and that typical "massive sulphide haloes" of high Zn, low Na, or association with volcaniclastics (Govett, 1983) were not apparent, at least on the scale of sampling used in the study (one sample per km^2). Thus, the massive sulphides in the East Amisk area appear to be associated with arc-type rocks, rather than with the major mid-Ti group which has MORB or within-plate affinities. Sorting the data from the other areas into low-Ti and -Nb groups does not produce any obvious geographic clusters that might present target areas for further exploration. Consequently, the East Amisk low-Ti group rocks and contained sulphides seem to be unique in the region.

Present sample coverage does not include the area close to the large Flin Flon Cu-Zn deposit. Clearly this is a prime location for future studies.

Geochemistry yields only equivocable interpretations concerning environments of gold mineralization, primarily because in general gold was not analyzed from samples collected in the southern region.

The Rio deposit and surrounding gold occurrences show little evidence of lithological (i.e., geochemical) control and field evidence suggests a predominantly structural association.

On the other hand, the Annabel Lake gold showing, where Au analyses are available for some of the rocks, can be linked spatially to volcanic rocks that have been altered and relatively enriched in Fe_2O_3, K_2O and V, and depleted in Ba, Nb, Rb and Sr (Parslow, in prep.). However, field observations indicate the rocks in the vicinity of the Annabel Lake showing are moderately to

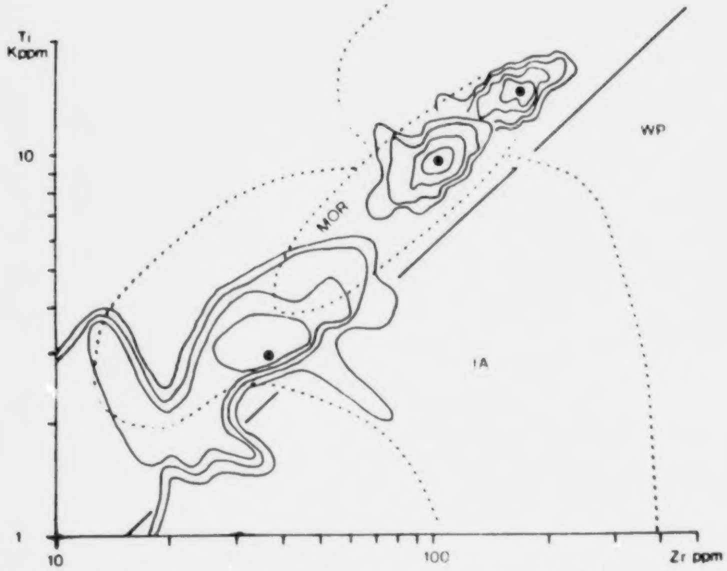

Figure 7 – Binary diagram of log Zr – log Ti showing the East Amisk "chemical" basalts as three subgroups: low-Ti, mid-Ti and high-Ti. The dots represent the average value and the contours define 0.5, 1.0, 1.5 and 2.0 standard deviations from the mean value (i.e., they enclose 34 percent, 68 percent, 86 percent and 95 percent, respectively, of the data in a given subset).

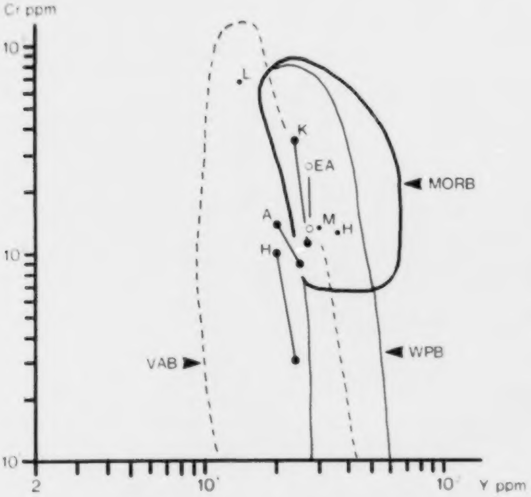

Figure 8 – Binary diagram of log Y – log Cr (after Pearce, 1980, 1982) used to discriminate between mid-ocean ridge basalts (MORB), arc basalts (VAB) and within-plate basalts (WPB). Data plotted are BAS and BAN for the various areas with the abbreviations (as in Figure 4) located at the BAS dot or circle. The East Amisk subsets of basalts are shown by small dots and marked L, M, and H for low-Ti, mid-Ti and high-Ti basalts, respectively.

strongly deformed, which again suggests the possibility of structural control. Similar enrichments and depletions observed in rocks in other areas do not define any clear pattern.

Although no sampling has been carried out in the region of the Laurel Lake gold deposit, its association with porphyry rocks and the presence of an alteration halo suggest that regional geochemistry may be fruitful in defining pathfinder signatures to be used in locating other similar deposits.

The gold showings in the Kisseynew Domain are similar to those in the Rio area in that specific lithological controls are not apparent. In particular, the very detailed sampling in the Manson Bay area close to a gold showing (M on Figure 2) revealed that *all* rocks were enriched in gold, but not in other elements, up to a distance of 300 m from the main zone, indicating that alteration haloes are not apparent from the geochemical data. On the other hand, evidence for tectonic deformation is moderate to strong. This area (measuring 2000 by 600 m, sampled every 50 m) has a mean gold value of 47 ppb with a standard deviation of 138 ppb. A tectonic control for the gold-bearing solutions appears more likely than lithological control. In regional terms, the average Au value (and standard deviation) for the 85 area (Figure 2) is 4(15) ppb, while around Manson Bay (the 86 area, Figure 2), it is 7(27) ppb, suggesting the existence of a rather weak regional gold anomaly.

4. Discussion and Conclusions

The following conclusions are drawn from the geochemical studies:

1) Rocks from the Flin Flon area are predominantly arc related, with tholeiitic and oceanic characteristics – Assuming that Proterozoic volcanic sequences reflect plate tectonic processes similar to those in the Phanerozoic and that alteration processes due to metamorphism have not destroyed igneous trends, the geochemical data suggest that the Flin Flon – Snow Lake volcanic sequence represents an island arc environment. Studies in Manitoba on the eastern portion of the belt (Bailes and Syme, 1987; Syme, 1987) are in agreement with this conclusion, including its tholeiitic and oceanic features. The general paucity of more evolved rocks (particularly andesites) and volcaniclastic rocks indicate a true oceanic arc with virtually no involvement of continental crust and limited subaerial volcanic activity. In the authors' view, the data support the hypothesis that the rocks represent the early stages of the development of an arc, although the possibility that more evolved rock sequences may have been removed by erosion after tectonism and prior to deposition of the overlying Missi molasse deposits cannot be discounted.

2) Rocks from the East Amisk area are unique to the study in that they are predominantly rift related – In terms of chemistry, the majority of the East Amisk rocks must be considered either MORB type or within-plate type, or both. The other areas do not show this characteristic. Although the authors favour a MORB origin, these rocks may also be interpreted as ophiolites, ocean island volcanics or back-arc basin rift volcanics. Other studies (e.g., Saunders and Tarney, 1979) suggest that geochemistry, especially without comprehensive REE analyses, is of limited use in discriminating such environments of formation. Ophiolitic and ridge rocks are readily identified geologically in Phanerozoic sequences by the presence of sheeted dyke swarms. On the other hand, the strongly deformed state of the volcanics in the East Amisk area would hinder the identification of such intrusive features. At present, only the general observations that gabbroic and ultrabasic rocks are common, that minor pentlandite is ubiquitous (Byers and Dahlstrom, 1954), and that an ultramafic-hosted Cu-Ni deposit occurs at Namew Lake some 50 km to the south, can be considered circumstantial evidence that the East Amisk area rocks are ridge related. Thus, although the East Amisk rocks are definitely tholeiitic, oceanic and rift related in character, their true nature remains an enigma. Certainly, if the arc-related rocks are considered to represent a "youthful" arc, then the presence and incorporation of pre-existing ocean floor into the folded sequence might be expected.

3) The Flin Flon – Snow Lake arc complex is geochemically distinct from the La Ronge volcanic arc – Although the two arcs are essentially coeval, at least from geochronological evidence (Van Schmus et al., 1987; Mukherjee et al., 1971; Bell et al., 1975), the observation that the La Ronge arc is calc-alkaline and contains much more volcaniclastic material as well as rocks indicative of a marginal continental arc association (Watters and Pearce, 1987) suggests a significant difference in environment of formation. A simple explanation is derived using Figure 1, wherein the broad regional picture is a craton in the northwest passing southeastwards into an oceanic area, with the La Ronge belt effectively on the continental boundary and the Flin Flon arc further out "in the ocean".

4) **The exact temporal relations between the Kisseynew Basin and the two arcs are still unresolved** – Current opinion is that the Kisseynew-type rocks are coeval with the two arc sequences (Ashton et al., 1987; Lewry, pers. comm.). Although the observed chemical signatures of the hornblende-bearing rocks in this high-grade terrain do not apparently refute this conclusion, neither do they *prove* that the Kisseynew terrain was coeval with the arc complexes. Any explanation of temporal and spatial relationships must consider: 1) the abrupt change in lithology between the low-grade Flin Flon rocks and the high-grade Kisseynew rocks; 2) the late Archean to early Proterozoic ages of rocks in the Sahli Gneiss dome and nearby McMillan Point granite in the Hanson Lake Block (Bell & Macdonald, 1982; Van Schmus et al., 1987) which are Kisseynew-type gneisses; and 3) The observation resulting from the present study of the rather high Cr values in the Kisseynew relative to Flin Flon volcanics and the transitional chemistry between oceanic and continental arc association. The abrupt grade change, change in lithology, and presence of a strong east-trending deformation zone between the Flin Flon and Kisseynew rocks can be explained by a model originally proposed by the authors (Parslow and Gaskarth, 1985) and recently refined by Lewry (in prep.). Based on a structural synthesis of the regional fold pattern, Lewry proposes that the Kisseynew/Amisk contact has been tectonically telescoped by the thrusting of the Kisseynew Gneisses over the southern volcanic sequence. The temporal dilemma remains, of course. The authors have shown, in the present study, that "volcanic" rocks in the Kisseynew Gneisses close to the Flin Flon arc are typically tholeiitic, possibly more distal volcanics in an interarc basin. By the same argument, "volcanic" rocks in the Kisseynew Basin close to the La Ronge arc should be as calc-alkaline as the La Ronge arc volcanics, assuming that they are related and coeval.

5) **Massive sulphide mineralization in the region is typically volcanogenic** – Sulphide mineralization in the southern area is common as either massive barren sulphides (pyrite and pyrrhotite) associated with mixed pyroclastic and pillowed basalts with some interbedded sediments (e.g., Annabel Lake area), or as similar massive sulphides containing variable amounts of Cu and Zn and associated with minor volcaniclastics and acid volcanics in thick sequences of pillowed basalts (e.g., East Amisk area). Although the large deposits have classically identifiable alteration haloes, the smaller deposits have very restricted geochemical haloes. The small deposits occur within a belt of low-Ti and -Nb volcanic

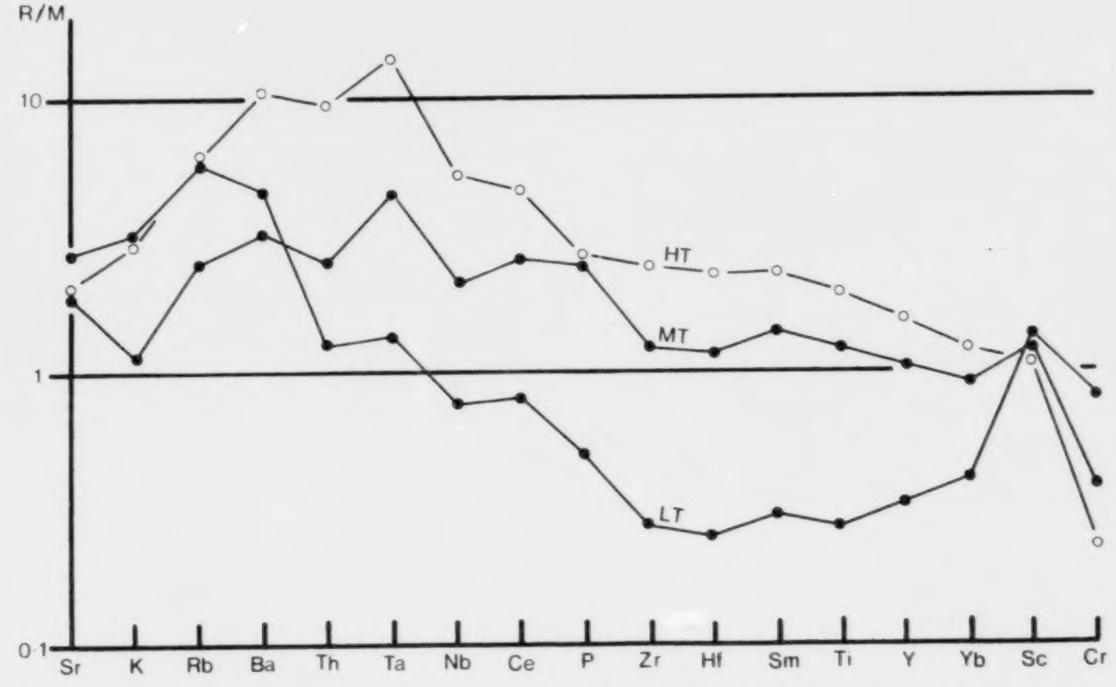

Figure 9 – MORB-normalized elemental patterns for the East Amisk basalt subsets (LT, MT, HT). An average of three analyses for each subset was used for the rock value/MORB (R/M). The MORB values (in ppm unless noted) used were Sr = 120, K_2O = 0.15 percent, Rb = 2, Ba = 20, Th = 0.2, Ta = 0.18, Nb = 3.5, Ce = 10, P_2O_5 = 0.12 percent, Zr = 90, Hf = 2.4, Sm = 3.3, TiO_2 = 1.5 percent, Y = 30, Yb = 3.4, Sc = 40, Cr = 250

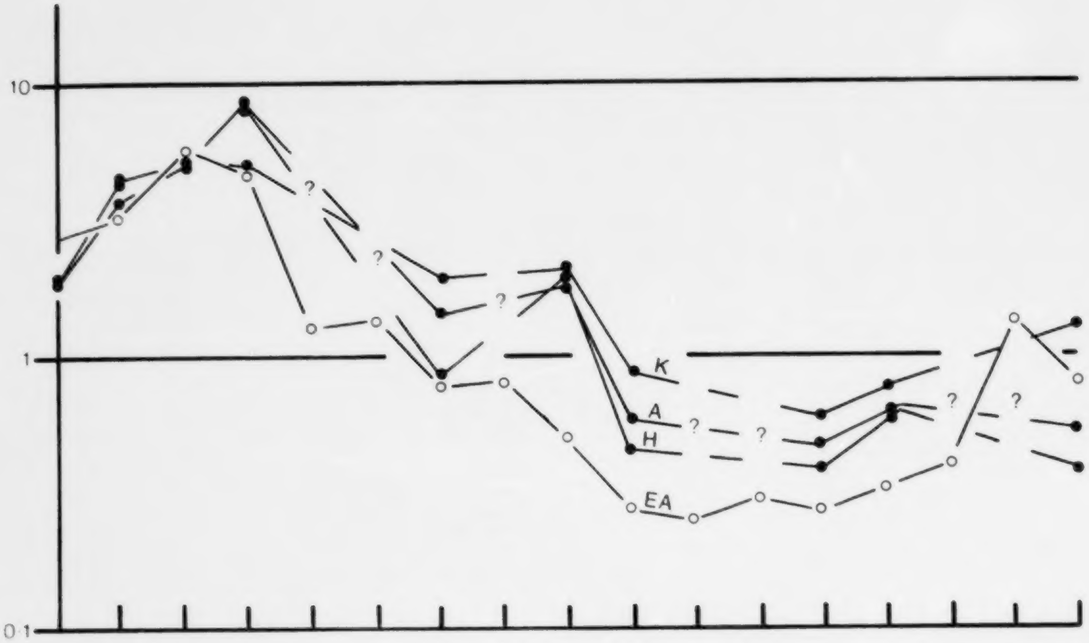

Figure 10 - MORB-normalized elemental patterns for the average basalt values of the Kisseynew (K), Annabel (A) and Hamell (H) areas, compared with the East Amisk low-Ti basalts (EA) from Figure 9. MORB values as in Figure 9.

rocks (flow, clastic and intrusive) that is unique in the areas studied.

Chemostratigraphic or lithostratigraphic correlations over large areas have proven difficult. To the east of the study area in Manitoba, detailed mapping (Syme, 1987) has shown that the Amisk Group is broken into numerous fault-bounded blocks which exhibit an internal consistency but lack correlatable units. It is likely that similar structural partitioning of volcanics characterizes the present study area and the Amisk Group as a whole.

Large massive sulphide deposits worthy of exploitation have not been found to date amongst the Kisseynew rocks. Even if these rocks were coeval with the Amisk and La Ronge volcanics, they probably represent a distal facies, and the thin units of "volcanics" are possibly less likely to host significant massive sulphides.

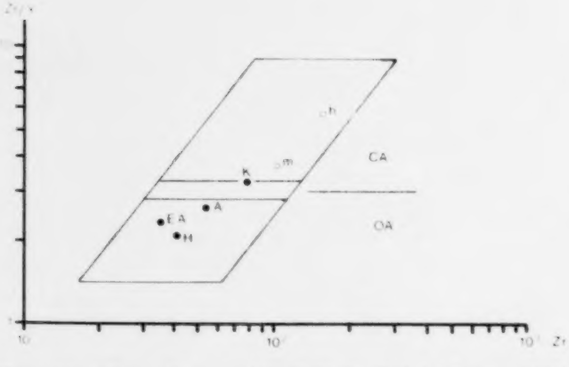

Figure 11 - Binary diagram of log Zr/Y - log Zr (after Pearce, 1983) used to discriminate between volcanic arcs of continental (CA) and oceanic (OA) association. Abbreviations as in Figure 4. Note that the EA point is the low-Ti average only, and that m and h denote the mid- and high-Ti basalts from the East Amisk area.

6) Gold mineralization in the region is essentially structurally controlled - All deposits exhibit strong structural control and only one, the Annabel Lake gold showing, has a clear recognizable alteration halo. This suggests that in any future exploration work the geochemical input will be reduced from a study of possible genetic models based on lithology and alteration to a simple analysis for Au in rocks associated with zones of intense deformation. An interesting observation is the general concordance of the M, K, A and D showings (Figure 2) in terms of structural level within the major interference structure. These showings may be outlining the locus of a major "folded" deformation zone in the Kisseynew Gneisses. If the Au is stucturally controlled, it is epigenetic.

5. Acknowledgements

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6. References

Ashton, K.E., Wheatley, K.J., Moser, D., Paul, D. and Wilcox, K.H. (1986): The Kisseynew Gneisses of Saskatchewan: update; *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep. 86-4, p145-148.

Ashton, K.E., Wilcox, K.H., Wheatley, K.J., Paul, D. and de Tombe, J. (1987): The boundary zone between the Flin Flon domain, Kisseynew Gneisses and Hanson Lake Block, northern Saskatchewan; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p131-134.

Ayres, L.D., van Wagoner, N. and van Wagoner, S. (1981): Physical volcanology of the Amisk Lake volcano; *in* Summary of Investigations 1981, Sask. Geol. Surv., Misc. Rep. 81-4, p47-51.

Bailes, A.H. (1980): Geology of the File Lake area; Manit. Dep. Energy Mines, Miner. Resour. Div., Geol. Rep. 78-1, 134p.

Bailes, A.H. and Syme, E.C. (1987): Geology of the Flin Flon–White Lake area; Manit. Energy Mines, Map GR87-1-1.

Bell, K. and Macdonald, R. (1982): Geochronological calibration of the Precambrian Shield in Saskatchewan; *in* Summary of Investigations 1982, Sask. Geol. Surv., Misc. Rep. 82-4, p17-22.

Bell, K., Blenkinsop, J. and Moore, J.M. (1975): Evidence for a Proterozoic greenstone belt from Snow Lake Manitoba; Nature, v258, p698-701.

Byers, A.R. and Dahlstrom, C.D.A. (1954): Geology and mineral deposits of the Amisk–Wildnest Lakes area, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 14, 177p.

Byers, A.R., Kirkland, S.J.T. and Pearson, W.J. (1965): Geology and mineral deposits of the Flin Flon area, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 62, 95p.

Cheesman, R.L. (1956): The geology of the Mari Lake area, northeastern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 23, 40p.

Coombe, W.C. (1979): Mineral deposits and regional metallogeny, southeastern shield; *in* Summary of Investigations 1979, Sask. Miner. Resour. Misc. Rep. 79-10, p120-133.

Davies, J.F., Grant, R.W.E. and Whiteheak, R.E.S. (1979): Immobile trace elements and Archean volcanic stratigraphy in the Timmins mining area, Ontario; Can. J. Earth Sci., v16, p305-311.

Froese, E. (1969). General geology of the Coronation Mine area; *in* Byers, A.R. (ed.), Symposium on the Geology of the Coronation Mine, Saskatchewan; Geol. Surv. Can., Pap. 68-5, p7-35.

Fumerton, S.L., Stauffer, M.R. and Lewry, J.F. (1984): The Wathaman batholith: largest known Precambrian pluton; Can. J. Earth Sci., v21, p1082-1097.

Gaskarth, J.W. and Parslow, G.R. (1987): Proterozoic volcanism in the Flin Flon greenstone belt, east-central Saskatchewan, Canada; Geol. Soc., Spec. Publ. 33, p183-200.

Govett, G.J.S. (1983): Rock Geochemistry in Mineral Exploration; Elsevier, Amsterdam, 461p.

Irvine, T.N. and Baragar, W.R.A. (1971): A guide to the chemical classification of the common volcanic rocks; Can. J. Earth Sci., v8, p523-548.

Jakes, P. and White, A.J.R. (1971): Composition of island arcs and continental growth; Earth Planet. Sci. Lett., v12, p224-230.

Johnson, R.L. (1966): The geology of the Nemei Lake area (west half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 107, 23p.

Koo, J. and Mossman, D.H. (1975): Origin and metamorphism of the Flin Flon stratabound Cu-Zn sulphide deposit, Saskatchewan and Manitoba, Canada; Econ. Geol., v70, p48-62.

Lewry, J.F. and Sibbald, T.I.I. (1980): Thermotectonic evolution of the Churchill Province in northern Saskatchewan; Tectonophysics, v68, p45-82.

Macdonald, R. (1975): Semi-reconnaissance in three areas, Pelican Narrows (63M); *in* Summary of Investigations 1975, Sask. Geol. Surv., p35-43.

McDougall, F.H., Watters, B.R. and Parslow, G.R. (1982): Mineral occurrences in the Precambrian of NTS areas 63K and 63L, Saskatchewan; Sask. Energy Mines, Open File Rep. 82-6, 492p.

Moore, J.M.Jr. (1977): Orogenic volcanism in the Proterozoic of Canada; Geol. Assoc. Can., Spec. Pap. 16, p127-148.

Mukherjee, A.C., Stauffer, M.R. and Baadsgaard, H. (1971): The Hudsonian Orogeny near Flin Flon, Manitoba: a tentative interpretation of Rb-Sr and K-Ar ages; Can. J. Earth Sci., v8, p939-946.

Parslow, G.R. (1986): Kisseynew metallotect geochemical study; *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep. 86-4, p84-96.

________ (1987): Lithogeochemical data from the East Amisk area of the Flin Flon–Snow Lake volcanic belt: implications for mineral exploration; J. Geochem. Explor., v28, p133-148.

Parslow, G.R. and Gaskarth, J.W. (1984): Geochemistry of the East Amisk area; Sask. Energy Mines, Open File Rep. 84-23, 156p.

________ (1985): Kisseynew metallotect geochemical study; *in* Summary of Investigations 1985, Sask. Geol. Surv., Misc. Rep. 85-4, p50-58.

________ (1986): Geochemistry of the Annabel Lake area; Sask. Energy Mines, Open File Rep. 86-3, 154p.

________ (1987): Geochemistry of the Hamell Lake area; Sask. Energy Mines, Open File Rep. 87-4, 73p.

Pearce, J.A. (1980): Geochemical evidence for the genesis and eruptive setting of lavas from Tethyan ophiolite; *in* Ophiolites, Proceedings of the International Ophiolite Symposium 1979; Geol. Surv. Dep., Cyprus, p261-272.

________ (1982): Trace element characteristics of lavas from destructive plate boundaries; *in* Andesites; John Wiley and Sons, p525-548.

________ (1983): Role of the sub-continental lithosphere in magma genesis at active continental margins; Conteport, v97, 39p.

Pearson, J.G. (1987): Gold mineralization in the Flin Flon–Amisk Lake area, Saskatchewan; Sask. Geol. Soc., Spec. Publ. 8, p37-43.

Pyke, M.W. (1961): The geology of the Attitti Lake area (west half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 54, 33p.

________ (1965): The geology of the Nemei Lake area (east half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 97, 39p.

Robertson, D.S. (1953): Batty Lake map-area, Manitoba; Geol. Surv. Can., Mem. 271, 55p.

Sangster, D.F. (1972): Precambrian volcanogenic massive sulphide deposits in Canada: a review; Geol. Surv. Can., Pap. 72-22, 44p.

Saunders, A.D. and Tarney, J. (1979): The geochemistry of basalts from a back-arc spreading centre in the Scotia Sea; Geochim. et Cosmochim. Acta, v43, p555-572.

Stauffer, M.R. (1984): Manikewan: an early Proterozoic ocean in central Canada, its igneous history and orogenic closure; Precambrian Res., v25, p257-281.

Stauffer, M.R., Mukherjee, A.C. and Koo, J. (1975): The Amisk Group: an Aphebian(?) island arc deposit; Can. J. Earth Sci., v12, p2021-2035.

Syme, E.C. (1987): Athapapuskow Lake project; *in* Report of Field Activities 1987, Manit. Energy Mines, p30-39.

Van Schmus, W.R., Bickford, M.E., Lewry, J.F. and Macdonald, R. (1987): U-Pb geochronology in the Trans-Hudson Orogen, northern Saskatchewan, Canada; Can. J. Earth Sci., v24, p407-424.

Walker, T. and McDougall, F. (1987): Geology of the Laurel Lake gold-silver deposit; Sask. Geol. Soc., Spec. Publ. 8, p44-53.

Watters, B.R. and Armstrong, R.L. (1985): Rb-Sr study of metavolcanic rocks from the La Ronge and Flin Flon domains, northern Saskatchewan; Can. J. Earth Sci., v22, p452-463.

Watters, B.R. and Pearce, J.A. (1987): Metavolcanic rocks of the La Ronge Domain in the Churchill Province, Saskatchewan: geochemical evidence for a volcanic arc origin; Geol. Soc., Spec. Publ. 33, p167-182.

Provincial Project in the Southern Precambrian under the Canada–Saskatchewan MDA 1984–89

Buried Precambrian Basement in South-Central Saskatchewan: Provisional Results from Sm-Nd Model Ages and U-Pb Zircon Geochronology[1]

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Collerson, K.D., Van Schmus, R.W., Lewry, J.F. and Bickford, M.E. (1988): Buried Precambrian basement in south-central Saskatchewan: provisional results from Sm-Nd model ages and U-Pb zircon geochronology; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

Sm-Nd isotopic data from Precambrian basement terrains have allowed constraints to be placed on the time of separation of continental crustal components from their mantle source regions (e.g., McCulloch and Wasserburg, 1978; Allegre and Ben Othman, 1980; DePaolo, 1981; McCulloch and Compston, 1981; Collerson and McCulloch, 1982; Patchett and Bridgwater, 1984; Wilson et al., 1985; Patchett and Kouvo, 1986; Chauvel et al., 1987). Such studies in Early Proterozoic orogenic belts have permitted distinctions to be made between reworked Archean crust and crust formed by the accretion of juvenile (short-lived, mantle-derived) magmatic arcs (Patchett and Bridgwater, 1984; Patchett and Kouvo, 1986).

1. Background to Present Study

Comprehensive U-Pb zircon geochronological studies in the eastern part of the Thelon Segment (Reindeer Zone) of the Trans-Hudson Orogen in Saskatchewan by Van Schmus et al., (1987a) and Lewry et al., (1986) have demonstrated that lithotectonic belts southeast of the Wathaman Batholith (Lewry et al., 1985) were formed largely by accretion of juvenile volcanic and magmatic arcs, and by docking of suspect terrains during a very short time interval (ca. 1830 to 1890 Ma). Reconnaissance Nd and Pb isotopic data for these juvenile terrains (Chauvel et al., 1987; Thom et al., 1987) indicate that some of them contain an older (Archean) crustal component. Evidence of this component appears to increase systematically from the La Ronge magmatic arc in the southeast to the Wathaman Batholith in the northwest. These isotope systematics are interpreted to reflect mixing between juvenile Proterozoic crust and variable amounts of Archean crust, via sedimentary and volcanoplutonic processes. In contrast, terrains west and northwest of the Wathaman Batholith are interpreted on geological evidence as containing substantial amounts of variably reworked Archean crust (Lewry et al., 1985). This area is considered to have been a relatively coherent cratonic platform while late Early Proterozoic crust was forming in the Reindeer Zone of the Trans-Hudson Orogen (Lewry et al., 1985).

Geological relationships in the La Ronge, Glennie and Kisseynew Domains of the Reindeer Zone have recently been interpreted as reflecting thin-skinned tectonic activity driven by crustal shortening during orogeny (i.e., the development and transportation of complex allochthonous fold/thrust stacks and fold nappes). Chiarenzelli et al. (1987) and Lewry et al. (in press) have shown that windows of Archean gneisses are exposed at lowest structural levels within the Glennie Domain and Hanson Lake Block. These important relationships indicate that much of the southeast part of the Reindeer Zone may be underlain by Archean crust that was overridden by allochthonous juvenile Proterozoic crust subsequent to arc formation during terminal collision within the orogen.

The almost entirely unexposed "Dakota Segment" of the Trans-Hudson Orogen extends southwards from the exposed Precambrian Shield through central and southern Saskatchewan into Montana and the Dakotas. An understanding of the geological evolution of this segment of the orogen is therefore of critical importance for tectonic models to explain the configuration of the North American Craton during the Early Proterozoic (cf. Hoffman, 1988). Previous petrological and geochemical studies of basement specimens recovered from drill core in this region have been carried out by King (1966), Burwash and Culbert (1976), Burwash and Cumming (1974), Burwash and Krupicka (1969, 1970), Burwash et al. (1962, 1973), Rosholt et al. (1970), Peterman and Hedge (1964), and Peterman and Goldich (1982).

2. Objectives of Present Study

We are currently re-examining basement core samples from central and southern Saskatchewan so as to interpret them in the context of: 1) established lithotectonic elements of the exposed Shield to the north (Lewry, 1981, 1984; Lewry et al., 1985; Lewry and Collerson, in press); 2) U-Pb zircon geochronology (Van Schmus et al., 1987a); 3) Sm-Nd and Pb systematics for rocks from the Thelon Segment of the Trans-Hudson Orogen in northern Saskatchewan (Chauvel et al., 1987; Thom et al., 1987; Collerson et al., in prep); and 4) available subsurface geophysical data (Dutch, 1983; Arvidson et al., 1984; Green et al., 1985a,b; Klasner and King 1986)). This report gives provisional results of a U-Pb zircon and Sm-Nd isotopic and petrographic study of selected

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core samples. It provides information on the time of separation of the protoliths of the basement rocks from their mantle source region and their subsequent crustal evolutionary histories. Results will complement studies of the basement of the Western Canadian Sedimentary Basin in Alberta and southern British Columbia (Frost and O'Nions 1984; Ross et al., 1988), and should also provide a more complete understanding of the geological evolution of the concealed mid-continental region of the North American Craton (cf. Peterman, 1981; Nelson and DePaolo, 1985; Van Schmus et al., 1986; Sims and Peterman, 1986; Frost and Burwash, 1986; Peterman and Futa, 1987).

3. Methods of Study

Polished thin sections of cored basement rocks were examined to assess the degree of alteration, rock type and metamorphic grade. This initial petrographic investigation was carried out in order to determine the extent to which basement rock types could be correlated with lithotectonic elements in the exposed Precambrian Shield, thereby allowing an assessment to be made by Green et al. (1985a and b) of basement structure based on geophysical data. Despite the small data base compared to the northern Shield, several interesting features were identified which are discussed below in terms of broad geographic subdivisions.

U-Pb analyses on zircons separated from small splits of core were carried out using standard techniques of U-Pb geochronology in the Isotope Geochemistry Laboratory at the University of Kansas (Van Schmus et al., 1987a). Ages were calculated using the decay constants recommended by Steiger and Jager (1977).

Sm-Nd separation chemistry was carried out at the University of California, Santa Cruz and mass spectrometric measurements were made at the U.S. Geological Survey, Menlo Park. Sm-Nd isotopic analyses were undertaken using procedures described by McCulloch and Chappell (1982). Samples weighing 70 to 100 mg were spiked with a mixed $^{149}Sm/^{150}Nd$ tracer prior to digestion to ensure spike equilibration. Following an initial open beaker evaporation, they were further decomposed with HF in teflon bombs for several days at a temperature of ca. 205°C. After removal from the oven, $HClO_4$ was added and the $HF/HClO_4$ mixture was evaporated to dryness. Remaining insoluble fluorides were digested by treating the samples with 6N HCl in teflon bombs. The HCl solution was partially evaporated and then diluted to ca. 1.0N, the concentration required for ion exchange chemistry. These bomb procedures were adopted to ensure total dissolution of such refractory REE-bearing phases as zircon and monazite. Duplicate analyses with these digestion techniques agree within analytical uncertainty for both $^{147}Sm/^{144}Nd$ and $^{143}Nd/^{144}Nd$. Fractionation of isotope ratios were corrected using $^{146}Nd/^{144}Nd = 0.7219$. The decay constant for ^{147}Sm is 6.54×10^{-12} a^{-1}. Model ages were calculated with respect to a depleted mantle with $\varepsilon_{Nd}^{4.6\ Ga} = 0$ and $\varepsilon_{Nd}^{0} = +10$ (Goldstein et al., 1984).

4. Lithological Descriptions

Basement cores investigated in this study are identified in Table 1 and located in Figure 1.

a) Northwestern Area

Cores from this area include one orthopyroxene-hornblende-bearing quartzofeldspathic gneiss (SASK-35), a granulite facies garnet-cordierite-sillimanite-K-feldspar-bearing pelitic gneiss (SASK-38), a garnet-hornblende-bearing felsic gneiss (SASK-41), a biotite-muscovite-microcline-bearing granitic gneiss (SASK-40) and an augen granitic gneiss (SASK-32). These samples and their grade of metamorphism are consistent with the geology of much of the exposed Cree Lake Zone and with its extrapolation to the south and southwest (Figure 2).

b) Southwestern Area

Basement rock types in this area include hornblende-bearing (amphibolite facies) mafic tonalitic gneiss (SASK-43), a massive orthoquartzite (SASK-42), and a variety of undeformed granites (SASK-39, -36, -34, -137, -24) and felsic volcanics or high-level porphyry intrusions (SASK-24, -29, -30).

Age and metamorphic grade of the quartzite are equivocal. However, the presence of traces of diopside and the nature of recrystallized microstructures indicate am-

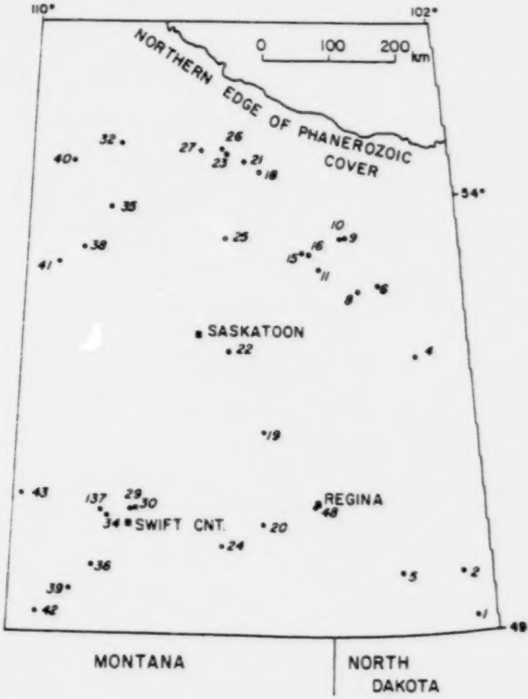

Figure 1 – Map showing distribution of specimens examined in this study.

Table 1 – Basement Core Samples from Saskatchewan

Spec. No.	*Location*	*Well Name*	*Lithology*
SASK-1	16-04-03-32W1	Socony Western Carievale	Granitic gneiss
SASK-2	8-30-08-33W1	SMUS South Parkman	Tonalitic gneiss
SASK-4	10-25-36-05W2	Ceepee Annette	Blastomylonite
SASK-5	3-27-08-08W2	Imp. Can. Superior Stoughton	Biotite-muscovite-cordierite gneiss
SASK-6	15-05-46-09W2	California Standard Bannock	Altered porphyritic microgranite
SASK-8	9-22-45-12W2	Peesane No. 2 Stratigraphic Test	Intermediate granulite
SASK-9	13-18-52-13W2	Triad Whitefox	Biotite-muscovite gneiss
SASK-10	12-15-52-14W2	Triad Whitefox	Garnet-cordierite-biotite-sillimanite gneiss
SASK-11	1-15-48-17W2	California Standard Ratner	Muscovite-biotite schist
SASK-15	8-09-50-18W2	Imperial et al., Fort à La Corne	Phyllite
SASK-16	4-10-50-18W2	Irex A	Banded iron formation
SASK-18	2-05-61-24W2	Great Plains Montreal Lake No. 25	Biotite-muscovite-garnet-carbonate-sulphide schist
SASK-19	1-14-10-27-25W2	Tide Water Stalwart Crown No. 1	Altered granite
SASK-20	2-11-15-26W2	Ceepee Baildon	Mesoperthite-biotite-bearing granite
SASK-21	5-22-62-26W2	Great Plains et al., Montreal Lake	Biotite-bearing tonalitic gneiss
SASK-22	4-16-37-01W3	White Roses et al., St. Denis	Granodiorite gneiss
SASK-23	3-18-63-01W3	Great Plains McDermott Home Hay	Garnet-biotite-sillimanite-cordierite gneiss
SASK-25	8-15-52-02W3	Mobil Oil von Mehren Lake X	Biotite-bearing tonalitic gneiss
SASK-26	8-08-64-02W3	Great Plains et al., Musquash	Biotite-bearing tonalitic gneiss
SASK-27	1-36-63-05W3	Great Plains et al., Smoothstone	Hornblende-biotite gneiss
SASK-29	1-09-17-14W3	B.A. Wilhelm	Hastingsite-bi-bearing microgranite
SASK-30	3-10-17-14W3	B.A. Sask Lndg Wilhelm	Porphyritic microgranite-rhyolite
SASK-32	8-30-64-15W3	Seaboard Meadow Lake Crown No. 3	Microcline-biotite granitic gneiss
SASK-34	2-21-16-17W3	M.U.S. Cantuar	Biotite-bearing microcline granite
SASK-35	7-14-56-17W3	Canadian Seaboard Divide No. 2	Charnockitic gneiss
SASK-36	2-04-10-19W3	Delhi et al., Rock Cr 2A	Granite
SASK-38	6-05-51-20W3	Husky D.H. Turtleford	Garnet-biotite-sillimanite-cordieite gneiss
SASK-39	9-32-06-22W3	M.O.W.S. Knollys	Albite granite
SASK-40	8-11-62-22W3	Imperial Goodsoil	Microcline-biotite granitic gneiss
SASK-41	6-01-49-24W3	Husky D.L. Lashburn	Garnet-biotite-plagioclase gneiss
SASK-42	4-31-03-26W3	Imperial et al., Battle Creek	Diopside-bearing quartzite
SASK-43	1-31-18-28W3	Mobile Oil North Richmond	Dioritic gneiss
SASK-48	3-08-17-19W2	Universiy of Regina	Megacrystic garnet-bearing granitic gneiss
SASK-137	15-03-17-18W2	Fosterton W.S. 15-3 "C"	Hastingsite-bearing granite

phibolite facies conditions of metamorphism. The quartzite yields a Nd crustal residence age of 2830 Ma (Frost and Burwash, 1986). This could be a provenance age and the unit could represent an Early Proterozoic shelf sequence, comparable with either the Snowy Pass Supergroup of the Medicine Bow Mountains in southeast Wyoming or parts of the Wollaston Group.

Significant and unexpected rock types in the southwest include posttectonic rapikivi granites, containing large compositionally zoned K-feldspar megacrysts, and porphyritic rhyolites considered to be high-level intrusives or extrusives. Ferrohastingsite appears in both the plutonics and the rhyolites. Previously published U-Th-Pb geochronological data for a granite from this suite indicated a crystallization age of ca. 1790 Ma (Rosholt et al., 1970). The same sample analyzed in this study has yielded a U-Pb zircon discordia age of 1763 ± 4 Ma (see below). Neodymium data for two of these granites (SASK-36, -39) reported by Frost and Burwash (1986) gave late Archean crust formation ages (2620 and 2580 Ma respectively). These data clearly indicate that the granites represent melts of Archean crust. The suite is tentatively correlated with post-Hudsonian anorogenic magmatism of the Dubawnt Group in the Thelon Segment of the Orogen (Donaldson, 1965; Blake, 1980) and provides a significant constraint on timing of tectonothermal activity in this part of the Orogen. Specimen distribution suggests that a major area of anorogenic plutonic and volcanic activity extends from Swift Current south towards Montana. This region, termed the **Swift Current Anorogenic Province** (Figure 2), lies on the northeasterly extension of the Great Falls Tectonic Zone (O'Neill and Lopez, 1985) which has been the locus of igneous activity and recurrent fault movements from Early or Mid-Proterozoic time through to the Holocene. It also straddles the postulated northeastern margin of the Archean Wyoming Craton.

c) South-Central Area

Cores from the Regina – Moose Jaw area (SASK-19, -20, -48) comprise weakly to moderately foliated, locally garnetiferous megacrystic and nonmegacrystic granites similar to rocks of the Wathaman Batholith.

Further east, the basement is characterized by tonalitic and granodioritic gneisses (SASK-27), medium- to high-grade supracrustal rocks (SASK-18, -21, -22, -23, -25, -26) and a variety of nondiagnostic pink granite and granodiorite. This marked change in lithological assemblage, similar to that occurring east of the exposed Wathaman Batholith, roughly coincides with the estimated position of the North American Central Plains

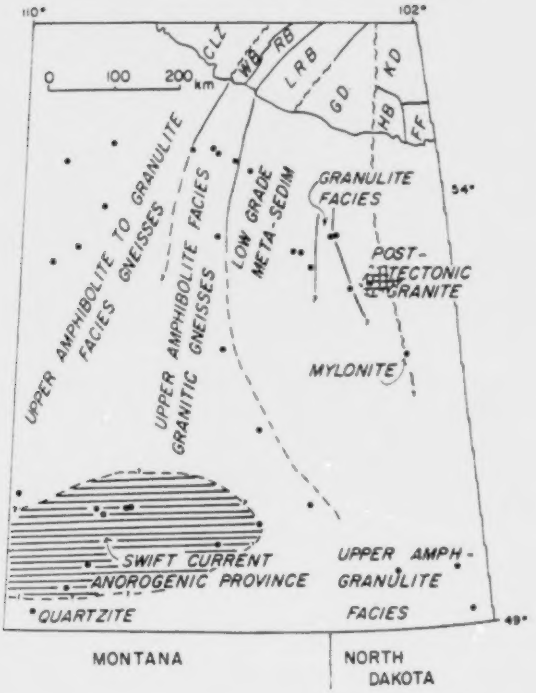

Figure 2 – Map showing variation in metamorphic grade and lithology in the sub-Phanerozoic basement in Saskatchewan.

Conductivity Anomaly (NACPCA) (Camfield and Gough, 1977).

d) Southeastern Area

Basement cores in the southeast include upper amphibolite to granulite facies tonalitic and granitic orthogneisses (SASK-2, -1), as well as cordierite-bearing gneiss (SASK-5) believed to be derived from a supracrustal sequence. There is no clear correlation between lithology and postulated geophysical boundaries. Two cores from North Dakota, immediately south of the Saskatchewan – United States border, contain zircons which yield U-Pb discordia intercept ages of ca. 2900 Ma, with lower intercepts of ca. 1650 to 1750 Ma (Peterman and Goldich, 1982). The cordierite gneiss SASK-5 from Imperial Stoughton 3-27 gives a Sr model age of ca. 2500 Ma (Peterman and Hedge, 1964).

e) North-Central and Northeastern Area

The north-central/northeastern part of the unexposed shield comprises granulite facies ortho- and paragneisses (SASK-4, -9, -10) and altered granite rich in accessory phases (SASK-6). These lie west of a blastomylonitic zone, tentatively related to the Trans-Hudson Orogen – Superior Province boundary zone, and west of the geophysically extrapolated subsurface extension of the Tabbernor Fault Zone. One extremely fresh intermediate granulite (SASK-8) has yielded abundant and virtually concordant zircon (see below). These high-grade rocks lie to the south of low-grade areas within the Glennie Domain. Their significance is currently unclear.

In the Choiceland area, west of this high-grade terrain, the metamorphic grade decreases abruptly. Several boreholes (SASK-11, -15, -16) intersect a low-grade metasedimentary assemblage that contains thick sequences of banded iron formation.

5. U-Pb Zircon Isotopic Results

U-Pb geochronological data for zircon fractions from several samples are presented in Table 2. Results are plotted in Figure 3.

Data from three fractions of SASK-2, a tonalitic gneiss, define a reasonable chord with a precise upper intercept of 1862 ± 4 Ma. Zircons from this sample are normal igneous-type zircons without cores or overgrowths. We interpret this age as dating primary crystallization of the tonalitic protolith.

Two fractions from the basic to intermediate granulite SASK-8 yield virtually identical and nearly concordant results; a chord passing through these two points and an assumed lower intercept of 500 Ma yields an upper intercept age of 1786 ± 4 Ma. This is only slightly older than the ^{207}Pb/^{206}Pb ages of the individual fractions and is insensitive to slope used for a discordia.

Four fractions of SASK-26 scatter significantly and yield a poorly defined upper intercept with an apparent age of 1914 ± 50 Ma. The zircons in these fractions contain distinct older cores. This result is within error of that obtained from HUD-83-17, a tonalitic gneiss in the Rottenstone Domain (Van Schmus et al., 1987a) which has yielded an apparent age of 1922 ± 24 Ma. Detailed processing of zircons from HUD-83-17, however, showed that the true U-Pb zircon age from a coreless fraction was ca. 1867 Ma, comparable to other plutonic units in the region. We therefore regard the apparent age of SASK-26 as a maximum metamorphic age, with

Table 2 – U-Pb Zircon Data for Basement Samples from Saskatchewan

Spec. No.	*Location*	*Lithology*	*Age (Ma)*[1]
SASK-2	8-30-08-33W1	Tonalitic gneiss	1862 ± 4
SASK-8	9-22-45-12W2	Intermediate granulite	1786 ± 4
SASK-26	8-08-64-02W3	Tonalitic gneiss	1914 ± 50
SASK-34	2-21-16-17W3	Posttectonic granite	1763 ± 4
SASK-35	7-14-56-17W3	Charnockitic gneiss	2484 ± 54
SASK-48	3-08-17-19W2	Megacrystic granitic gneiss	1822 ± 16

[1] Error given at 2σ confidence level

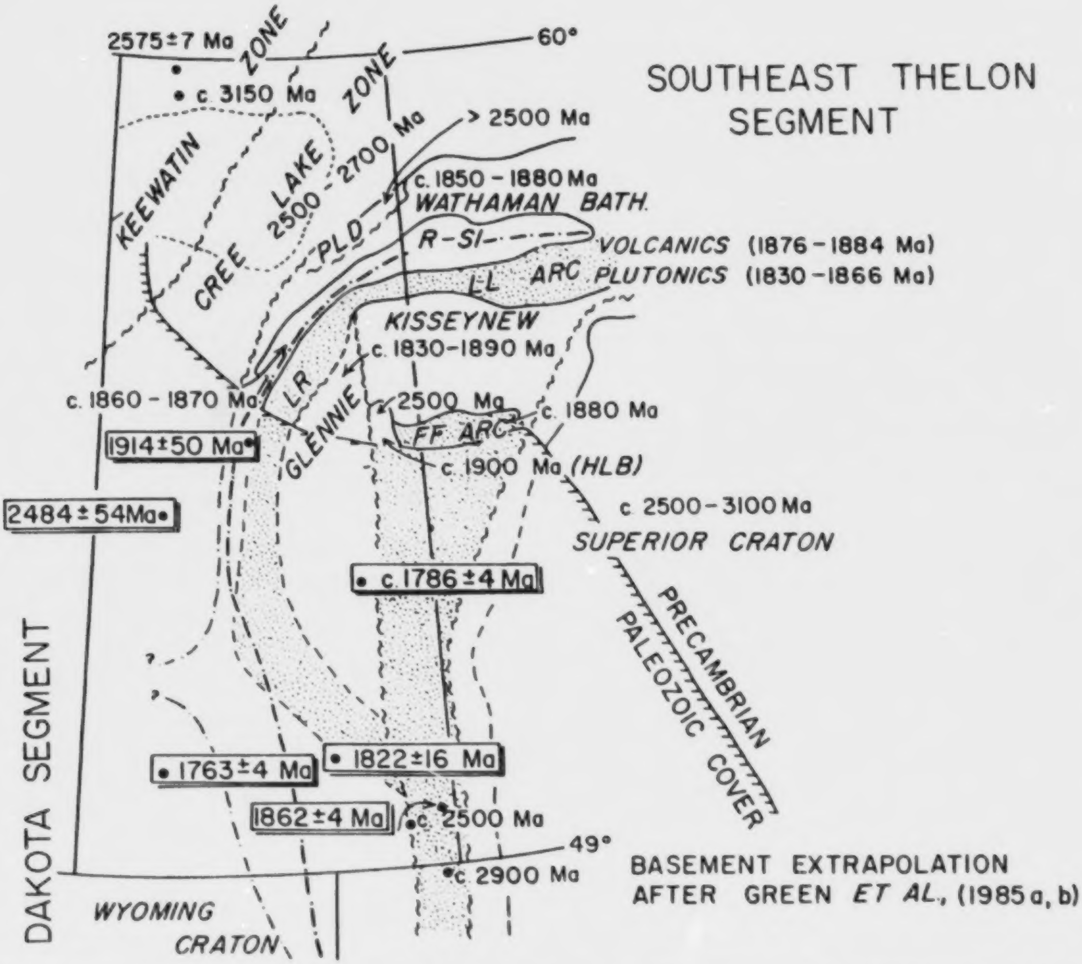
SOUTHEAST THELON SEGMENT
2575±7 Ma
c. 3150 Ma
60°
ZONE
ZONE
> 2500 Ma
KEEWATIN
CREE LAKE
2500 - 2700 Ma
c. 1850 - 1880 Ma
WATHAMAN BATH.
PLD
R-SI
VOLCANICS (1876-1884 Ma)
LL ARC
PLUTONICS (1830-1866 Ma)
KISSEYNEW
c. 1830-1890 Ma
c. 1860 - 1870 Ma
LR
GLENNIE
2500 Ma
c. 1880 Ma
FF ARC
1914±50 Ma
c. 1900 Ma (HLB)
2484±54Ma
c. 2500-3100 Ma
SUPERIOR CRATON
c. 1786±4 Ma
PRECAMBRIAN
PALEOZOIC COVER
DAKOTA SEGMENT
1763±4 Ma
1822±16 Ma
1862±4 Ma
c. 2500 Ma
49°
c. 2900 Ma
BASEMENT EXTRAPOLATION AFTER GREEN ET AL., (1985 a, b)
WYOMING CRATON
?
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Figure 3 - Map showing previous geochronological data for the exposed shield and variation in U-Pb zircon age determinations for the sub-Phanerozoic basement.

the probable age closer to 1850 to 1870 Ma, based on the probable correlation of this sample with the Rottenstone Domain to the north. Unfortunately there are insufficient zircons to prepare a hand-picked coreless fraction for this sample.

Three fractions of zircons from SASK-34 yield a moderate to very discordant result, although they are nearly colinear and give a relatively precise upper intercept age of 1763 ± 4 Ma. However, since only three fractions are used and the data are very discordant, this age should be regarded as less certain than quoted. In any case, it appears that the age of this granite is very similar to the Pb-Pb total rock - microcline age and two point Rb-Sr age (1790 Ma and 1772 ± 50 Ma respectively) reported from the same drillhole by Rosholt et al., (1970). It is therefore distinctly younger than that typical of granites from the Trans-Hudson Orogen (ca. 1830 to 1880 Ma; Van Schmus et al., 1987a).

Five fractions from SASK-35 are only slightly discordant and form a short linear array with an upper intercept of 2484 ± 54 Ma. The large uncertainty results from the lack of "leverage" on the chord defined by the data in combination with a relatively high lower intercept. These features cause the chord to be subparallel to concordia at the upper end. Results on this sample are similar to those from the Sahli Granite in the Hanson Lake Block (HUD-83-8; Van Schmus et al., 1987a) which also shows evidence of a Late Archean to Early Proterozic thermotectonic event.

Three discordant fractions from SASK-48 define an upper intercept of 1822 ± 6 Ma, but as in the case SASK-34, we consider this to be a minimum age. This sample is probably comparable in age to plutons of the Trans-Hudson Orogen at 1830 to 1870 Ma (Van Schmus et al., 1987a).

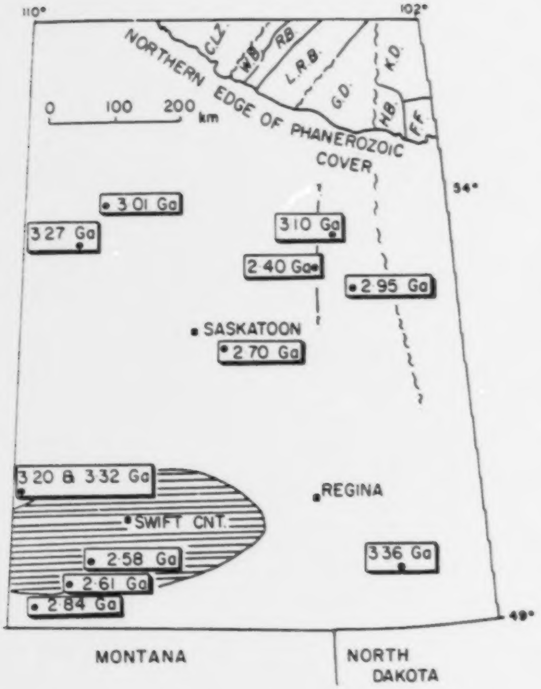

Figure 4 – Map showing crustal residence Nd model age data for basement samples.

6. Sm-Nd Isotopic Results

Sm-Nd isotopic data have been obtained for a reconnaissance suite of samples. Provisional crustal residence ages are presented in Figure 4. Crust formation ages ranging from ca. 3.4 Ga to 2.4 Ga for basement core samples show that the sub-Phanerozoic extension of the Trans-Hudson orogen is apparently not dominated by juvenile (ca. 1890 Ma) crust as suggested by Green et al., (1985a and b), or by Patchett and Arndt (1986). Instead, it appears to be dominated by Archean crust, albeit variably reworked by Hudsonian thermotectonism which produced growth of metamorphic zircon and the crystallization of zircon in penecontemporaneous crustal melts derived from source regions containing large volumes of earlier crust.

Nd isotopic data from the exposed Precambrian Shield in Saskatchewan (Chauvel et al., 1987; Collerson, unpublished data) are compared to data from the buried basement in Figure 5. Present-day ε_{Nd} values (DePaolo and Wasserburg, 1976) for the basement samples range from -21.5 to -34.4. In contrast, present-day ε_{Nd} values for juvenile Proterozoic rocks from the La Ronge Belt with broadly similar Sm/Nd ratios range from -15.6 to -23.3. The only suites that have present-day ε_{Nd} values similar to the basement data are the Sahli Granite in the Hanson Lake Block, and gneisses from the Rottenstone Domain, the Wathaman Batholith, the Peter Lake Domain, the Cree Lake Zone and Western Granulite Domain. Rocks in all these suites have Archean protoliths or are interpreted as having sources containing mixed Archean and Early Proterozoic components.

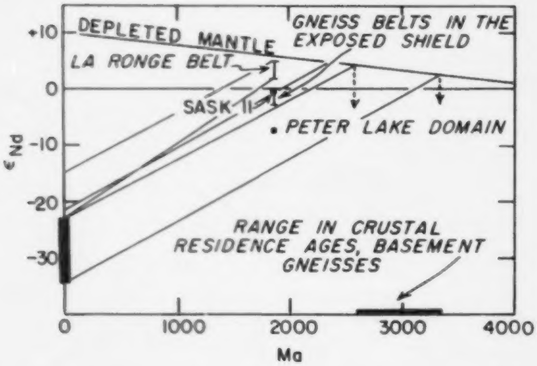

Figure 5 – ε_{Nd} versus time diagram showing comparison between the Nd isotope systematics of juvenile Proterozoic rocks from the La Ronge Belt, the Rottenstone Belt and Peter Lake Domain gneisses (Chauvel et al., 1986) and data for samples from the buried basement.

Also shown in Figure 5 are initial ε_{Nd} values calculated at 1.89 Ga. Negative ε_{Nd} values for the basement gneisses at this time clearly reflect the role of Archean crust. In contrast, positive ε_{Nd} values for juvenile Proterozoic rocks in the La Ronge Belt reflect the involvement of melts derived from depleted mantle sources. The only basement sample that possibly contains a Proterozoic crustal component is SASK-11, a biotite-muscovite schist which lies south of the Glennie Domain.

7. Discussion

Nd model ages give an estimate of the time that has elapsed since a crustal rock had the same $^{143}Nd/^{144}Nd$ ratio as its mantle source region. The approach assumes that there was only a short time interval between addition of material to the continental crust and fractionation of Sm/Nd during partial melting. Model ages are

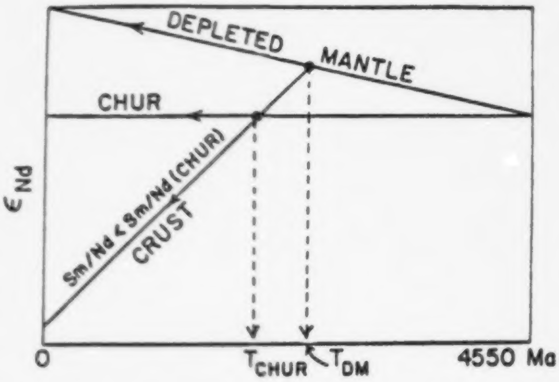

Figure 6 – ε_{Nd} versus time diagram showing graphical representation of Nd model ages assuming closed system evolution.

only valid if the assumptions concerning the source from which the crustal melts are derived are correct (Arndt and Goldstein, 1987). Initial $^{143}Nd/^{144}Nd$ ratios obtained for mantle-derived Archean and Proterozoic suites indicate derivation from light, rare earth-depleted mantle (DM) source regions with Sm/Nd ratios greater than that of a mantle reservoir with a chondritic Sm/Nd ratio (CHUR). This increase in Sm/Nd in the mantle is considered to be the result of depletion in Nd due to prior crust removal (McCulloch and Compston, 1981). The effect of this on the calculated model ages can be seen in Figure 6.

Although it has generally been considered that the Sm-Nd isotopic system is little affected by crustal processes, some fractionation of Sm/Nd ratio may occur under both metamorphic and anatectic conditions on both a mineralogical and whole rock scale (e.g., McCulloch and Black, 1984; Wilson et al., 1985; Collerson et al., 1988). As a result, Sm-Nd model ages may yield equivocal information about the time of crust generation and crustal residence.

The effect of isotopic homogenization due to redistribution of Nd and/or Sm during metamorphism will depend to a large degree on the scale of diffusion in relation to the scale of sample volume. The closed system evolution of two comagmatic rocks (wr_1 and wr_2) with different Sm/Nd ratios between the time of crust formation ca. 3400 Ma ago from a depleted mantle source and a period of metamorphism ca. 2700 Ma ago is shown in Figure 7. Both rocks evolve to negative ε_{Nd} values at T_{META}, because their Sm/Nd ratios are less than CHUR. During metamorphism, re-equilibration causes a decrease in the ε_{Nd} of WR_2 and an increase in the ε_{Nd} of WR_1 as a result of isotopic exchange. At the termination of the metamorphic event, the isochron is essentially reset to zero slope with a new initial $^{143}Nd/^{144}Nd$ ratio $I_{Nd}(2)$ controlled by the average ε_{Nd} of WR_1 and WR_2. The slope of the secondary isochron gives the age of T_{META}. In this analysis, the value of εNd (T_{META}) is a minimum value if the Sm/Nd ratios of the whole rock samples are less than CHUR. Samples with ε_{Nd} values <0 like those exhibited by the basement data usually represent rocks with a significant crustal prehistory.

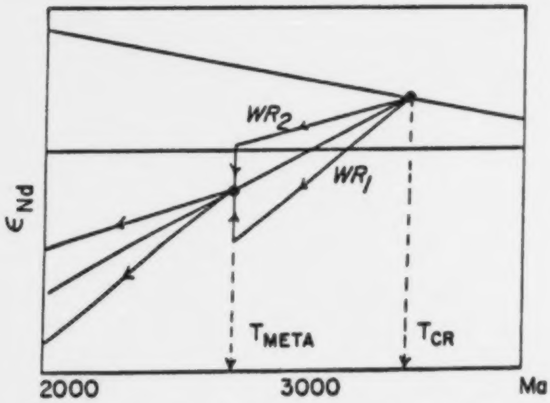

Figure 7 – εNd versus time diagram showing possible effect of later metamorphism on Nd isotope systematics.

8. Conclusions

1) The buried basement in southern and central Saskatchewan appears to contain a significant Archean crustal component which was variably affected by Hudsonian thermotectonism.

2) Superior Province Archean crust occurs further west than had been previously thought on the basis of geophysical data (cf. Green et al., 1985a and b).

3) Late Hudsonian evolution in the Dakota Segment of the Trans-Hudson Orogen probably involved transcurrent movement in which the arc terrains exposed in the north were dismembered and obliterated (cf. Green et al., 1985a and b).

4) The Swift Current Anorogenic Province shows widespread evidence of partial melting of Archean crust during a late Hudsonian or post-Hudsonian event ca. 1760 Ma ago.

The presence of widespread Archean crust within the buried basement in central and southern Saskatchewan places severe constraints on 1) tectonic models for the evolution of the Trans-Hudson Orogen, 2) the extrapolation of lithotectonic elements within the buried basement based on geophysical data (cf. Green et al., 1985a and b), and 3) estimates of the volume of juvenile crust added to the continental crust during the Early Proterozoic (cf. Patchett and Arndt, 1986).

9. Acknowledgements

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10. References

Allegre, C.J. and Ben Othman, D. (1980): Nd-Sm isotopic relationship in granitoid rocks and continental crust development: a chemical approach to orogenesis; Nature, v286, p335-342.

Arndt, N.T. and Goldstein, S.L. (1987): Use and abuse of crust formation ages; Geology, v15, p893-895.

Arvidson, R.E., Bindschadler, D., Bowring, S., Eddy, M., Guinness, E. and Leff, C. (1984): Bouguer images of the North American craton and its structural evolution; Nature, v311, p241-243.

Blake, D.H., (1980): Volcanic rocks of the Paleohelikian Dubawnt Group in the Baker Lake – Angikuni Lake areas, District of Keewatin, N.W.T.; Geol. Surv. Can., Pap. 309.

Burwash, R.A. and Culbert, R.R. (1976): Multivariate geochemical and mineral patterns in the Precambrian basement of western Canada; Can. J. Earth Sci., v13, p1-18.

Burwash, R.A. and Cumming, G.L. (1974): Helium source-rock in southwestern Saskatchewan; Bull. Can. Petrol. Geol., v22, p405-412.

Burwash, R.A. and Krupicka, J. (1969): Cratonic reactivation in the Precambrian basement of western Canada: I. Deformation and chemistry; Can. J. Earth Sci., v6, p1381-1396.

Burwash, R.A. and Krupicka, J. (1970): Cratonic reactivation in the Precambrian basement of western Canada: II. Metasomatism and isostasy; Can. J. Earth Sci., v7, p1275-1294.

Burwash, R.A., Baadsgaard, H. and Peterman, Z.E. (1962): Precambrian K-Ar dates from the Western Canada Sedimentary Basin; J. Geophys. Res., v67, p1617-1625.

Burwash, R.A., Krupicka, J. and Culbert, R.R. (1973): Cratonic reactivation in the Precambrian basement of western Canada: III. Crustal evolution; Can. J. Earth Sci., v10, p283-291.

Camfield, P.A. and Gough, D.I. (1977): A possible Proterozoic plate boundary in North America; Can. J. Earth Sci., v14, p1229-1238.

Chauvel, C., Arndt, N.T., Kielinzcuk, S. and Thom, A. (1987): Formation of Canadian 1.9 Ga old continental crust 1: Nd isotopic data; Can. J. Earth Sci., v24, p396-406.

Chiarenzelli, J.R., Lewry, J.F. and Landon, M. (1987): Bedrock geology, Iskwatikan Lake area: evidence for Hudsonian juxtaposition of Proterozoic and Archean rocks along a ductile detachment surface; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p46-51.

Collerson, K.D. and McCulloch, M.T. (1982): The origin and evolution of Archean crust as inferred from Nd, Sr and Pb isotopic studies in Labrador (abstract); Fifth Internat. Conf. Geochron., Cosmochron. and Isotope Geochem., Abstr., p61-62.

Collerson K.D., McCulloch, M.T. and Nutman, A.P. (1988): Sr and Nd isotope systematics of polymetamorphic gneisses from southern West Greenland and northern Labrador; Can. J. Earth Sci. (in press).

Donaldson, J.A. (1965): The Dubawnt Group, District of Keewatin and Mackenzie; Geol. Surv. Can., Pap. 64-20.

DePaolo, D.J. (1981): Neodymium isotopes in the Colorado Front Range and crust-mantle evolution in the Proterozoic; Nature, v291, p193-196.

DePaolo D.J. and Wasserburg, G.J. (1976): Nd isotopic variations and petrogenetic models; Geophys. Res. Lett., v3, p249-252.

Dutch, S.I. (1983): Proterozoic structural provinces in the north-central United States; Geology, v11, p478-481.

Frost, C.D. and Burwash, R.A. (1986): Nd evidence for extensive Archean basement in the western Churchill Province, Canada; Can. J. Earth Sci., v23, p1433-1437.

Frost, C.D. and O'Nions, R.K. (1984): Nd evidence for Proterozoic crustal development in the Belt – Purcell Supergroup; Nature, v312, p53-56.

Goldstein, S.L., O'Nions, R.K. and Hamilton, P.J. (1984): A Sm-Nd isotopic study of atmospheric dust and particulates from major river systems; Earth Planet. Sci. Lett., v70, p221-236.

Green, A.G., Hajnal, Z. and Weber, W. (1985a): An evolutionary model of the western Churchill Province and western margin of the Superior Province in Canada and the north-central United States; Tectonophysics, v116, p281-322.

Green, A.G., Weber, W. and Hajnal, Z. (1985b): Evolution of Proterozoic terrains beneath the Williston Basin; Geology, v13, p624-628.

Hoffman, P.F. (1988): United plates of America, the birth of a craton: Early Proterozoic assembly and growth of Laurentia; Annu. Rev. Earth Planet. Sci., v16, p543-603.

Jacobsen, S.B. and Wasserburg, G.J. (1980): Sm-Nd evolution of chondrites; Earth Planet. Sci. Lett., v50, p139-155.

King, H.L. (1966): Subsurface Precambrian of Saskatchewan; unpubl. M.A. thesis, Univ. Sask., 117p.

Klasner, J.S. and King, E.R. (1986) Precambrian basement geology of North and South Dakota; Can. J. Earth Sci., v23, p1083-1102.

Lewry, J.F. (1981): Lower Proterozoic arc-microcontinent collisional tectonics in the western Churchill Province; Nature, v294, p69-72.

Lewry, J.F. (1984): Continental platforms and suspect terrains in the Lower Proterozoic Trans-Hudson Orogen; Geol. Assoc. Can., Prog. Abstr., v9, p84.

Lewry, J.F. and Collerson, K.D. (in press): The Trans-Hudson Orogen: extent, subdivision and problems; *in* Lewry, J.F. and Stauffer, M.R. (eds.), The Early Proterozoic Trans-Hudson Orogen: Lithotectonic Correlations and Evolution; Geol. Assoc. Can., Spec. Pap.

Lewry, J.F., Sibbald, T.I.I., and Schledewitz, D.C.P. (1985): Variations in character of Archean rocks in the Western Churchill Province and its significance; *in* Ayres, L.D., Thurston, P.C., Card, K.D., and Weber, W. (eds.), Evolution of Archean Supracrustal Sequences; Geol. Assoc. Can., Spec. Pap. 28, p239-261.

Lewry, J.F., Collerson, K.D., Bickford, M.E. and Van Schmus, W.R. (1986): An evolutionary model of the western Churchill Province and western margin of the Superior Province in Canada and the north-central United States — discussion; Tectonophysics, v131, p183-197.

Lewry, J.F., Thomas, D.J., Macdonald, R. and Chiarenzelli, J. (in press): Structural relations in accreted terranes of the Trans-Hudson Orogen, Saskatchewan: telescoping in a collisional regime? *in* Lewry, J.F. and Stauffer, M.R. (eds.), The Early Proterozoic Trans-Hudson Orogen: Lithotectonic Correlations and Evolution; Geol. Assoc. Can., Spec. Pap.

McCulloch, M.T. and Black, L.P. (1984): Sm-Nd isotope systematics of Enderby Land granulites and evidence of the redistribution of Sm and Nd during metamorphism; Earth Planet. Sci. Lett., v1, p46-58.

McCulloch, M.T. and Chappell, B.W. (1982): Nd isotopic characteristics of S and I type granites; Earth Planet. Sci. Lett., v58, p51-64.

McCulloch, M.T. and Compston, W. (1981): Sm-Nd age of Kambalda and Kanowna greenstone and heterogeneity in the Archaean mantle; Nature, v294, p322-327.

McCulloch, M.T. and Wasserburg, G.J. (1978): Sm-Nd and Rb-Sr chronology of continental crust formation; Science, v200, p1003-1011.

Nelson, B.K. and DePaolo, D.J. (1985): Rapid production of continental crust 1.7 to 1.9 b.y. ago: Nd isotopic evidence from the basement of the North American mid-continent; Geol. Soc. Am. Bull., v96, p746-754.

O'Niell, J.M. and Lopez, D.A. (1985): Character and regional significance of Great Falls Tectonic Zone, east-central Idaho and west-central Montana; Am. Assoc. Petrol. Geol., v69, p437-447.

Patchett, P.J. and Arndt, N.T. (1986): Nd isotopes and tectonics of 1.9 - 1.7 Ga crustal genesis; Earth Planet. Sci. Lett., v78, p329-338.

Patchett, P.J. and Bridgwater, D. (1984): Origin of continental crust of 1.9 - 1.7 Ga age defined by Nd isotopes in the Ketilidian terrain of south Greenland; Contrib. Mineral. Petrol., v87, p311-318.

Patchett P.J. and Kouvo, O. (1986): Origin of continental crust of 1.9-1.7 Ga age: Nd isotopes and U-Pb zircon ages in the Svecokarelian terrain of South Finland; Contrib. Mineral. Petrol., v92, p1-12.

Peterman, Z.E. (1981): Dating of Archean basement in northeastern Wyoming and southern Montana; Geol. Soc. Am. Bull., v92, p139-146.

Peterman, Z.E. and Hedge, C.E. (1964): Age of basement rocks from the Williston Basin of North Dakota and adjacent areas; U.S. Geol. Surv., Prof. Pap. 475D, pD100-D104.

Peterman, Z.E. and Goldich, S.S. (1982): Archean rocks of the Churchill basement, Williston Basin, North Dakota; *in* Christopher, J.E. and Kaldi, J. (eds.), Fourth International Williston Basin Symposium Proceedings; Sask. Geol. Soc., Spec. Publ. 6, p11-12.

Peterman, Z.E. and Futa, K. (1987): Is the Archean Wyoming province exotic to the Superior Craton? Evidence from Sm-Nd model ages of basement cores; Geol. Soc. Am., Prog. Abstr., v19, p803.

Rosholt, J.N., Peterman, Z.E., and Bartel, A.J. (1970): U-Th-Pb and Rb-Sr ages in granite reference sample from southwestern Saskatchewan; Can. J. Earth Sci., v7, p184-187.

Ross, G.M., Parrish, R.R. Bowring, S.A. and Tankard, A.J. (1988): Tectonics of the Canadian Shield in the Alberta subsurface; Geol. Assoc. Can., Prog. Abstr., v13, p106.

Sims, P.K. and Peterman, Z.E. (1986): Early Proterozoic Central Plains Orogen: a major buried stucture in the north-central United States; Geology., v14, p488-491.

Steiger, R.H. and Jager, E. (1977): Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology; Earth Planet. Sci. Lett., v36, p359-362.

Thom, A., Arndt, N.T. and Chauvel, C. (1987): Volcanic arcs and granitoids in the Reindeer Zone, Saskatchewan; Geol. Assoc. Can., Prog. Abstr., v12, p95.

Van Schmus, W.R., Bickford, M.E., Lewry, J.F. and Macdonald, R. (1987a): U-Pb geochronology of the Trans-Hudson Orogen in northern Saskatchewan; Can. J. Earth Sci., v24, p407-424.

Van Schmus, W.R., Bickford, M.E. and Zietz, I. (1987b): Early and Middle Proterozoic Provinces in the central United States; *in* Kroner, A. (ed.), Proterozoic Lithospheric Evolution; Am. Geophys. Union, Geodynamic Ser., p43-68.

Wilson, M.R., Hamilton, P.J., Fallick, A.E., Aftalion, M. and Michard, A. (1985): Granites and early Proterozoic crustal evolution in Sweden: evidence from Sm-Nd, U-Pb and O isotope systematics; Earth Planet. Sci. Lett., v72, p376-388.

Federal-Provincial Project in Northern Saskatchewan under the Canada-Saskatchewan MDA 1984-89

Investigation of Mafic and Ultramafic Rocks for Nickel-Copper and Platinum Group Elements in Northern Saskatchewan: Preliminary Findings[1]

Larry Hulbert[2]

Hulbert, L. (1988): Investigation of mafic and ultramafic rocks for nickel-copper and platinum group elements in Northern Saskatchewan: preliminary findings; *in* Summary of Investigations 1988; Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

During the 1988 field season, mafic and ultramafic rocks in the Stony Rapids, Axis Lake, Currie Lake and Reeve Lake areas were investigated for their Ni-Cu and platinum group element (PGE) potential. High-grade PGE mineralization (from the U-Au-PGE association) was again sampled in the Greater Beaverlodge area for further mineralogical studies. In addition to the above field investigations, laboratory geochemical, geochronological and mineralogical studies have been in progress during the period from April 1 to September 30.

1. Field Work

a) Axis Lake, Currie Lake and Stony Rapids Area

Mafic and ultramafic rocks of the so-called "Noritic Series" (Kranck, 1955) are abundant in the Axis Lake, Currie Lake and Stony Rapids area. Similar rocks are found over a very large area, which extends from north of the mouth of the Fond-du-Lac River at the east end of Lake Athabasca to the Lytle Lake area east of Stony Rapids.

At Currie Lake and Axis Lake, these "noritic" bodies are known to contain massive and disseminated Ni-Cu sulphides (Colborne, 1960, 1962). Field examination indicates clearly that they are metamorphosed differentiated sills ranging in composition from norite to orthopyroxenite. A preferential concentration of massive sulphides and relict net-textured sulphides along their south margins suggest a north-facing direction.

Examination and sampling of outcrops north of the town of Stony Rapids revealed similar rocks, predominantly orthopyroxenite and minor norite containing up to 5 percent disseminated sulphides.

It should be noted that these areas appear to have been metamorphosed to the granulite facies. The preservation of original magmatic textures is attributed to the lack of volume change in the norites and othopyroxenites. The original magmatic mineralogy in these rocks (orthopyroxene and plagioclase) is typical of the granulite facies.

The highest PGE assays occur at Currie Lake, although these values are not anomalous compared to other sulphide deposits with similar Ni and Cu grades. Considerably lower PGE values were obtained from Axis Lake and the Stony Rapids area (Table 1).

Table 1 - PGE Values (in ppb) in Mafic-Ultramafic Rocks East of Lake Athabasca

	Currie Lake	*Axis Lake*	*Stony Rapids*
Pd	85-220	<5-33	<5
Pt	44-190	<5-33	<5
Ir	5.5-22	<0.1-2.0	0.2-0.4
Os	5-21	<2	<2
Ru	8-50	<5-8	<5
Rh	11-32	<1-4	<1
Au	32-120	14-79	4.6-9.1
n[1]	7	8	3

[1] number of samples

Although economic concentrations of PGE are not associated with the Ni-Cu-Co mineralization, the potential of this area for the latter should not be overlooked. Drilling at Currie Lake in 1957 discovered significant mineralization in one of four holes, a 7 m width averaging 1.03 percent Ni, 0.22 percent Cu, and local values reaching 2.53 percent Ni and 0.6 percent Co (Colborne, 1962). Since thin sill-like bodies (< 100 m) contain Ni-Cu-Co sulphide mineralization of the observed grade, the possibility of discovering commercial deposits of this type should be considered, especially in the thicker noritic to pyroxenitic bodies. North of the Fond-du-Lac River in the Stony Rapids area, these rocks form an approximately 8000 m thick series which occupies the centre of a large open syncline (Colborne, 1960).

b) Reeve Lake

Mackenzie diabase dykes were examined and sampled at Reeve Lake, 30 km north of Stony Rapids, as part of an ongoing study of the geology, geochemistry and Cu-Ni-PGE potential of the Mackenzie magmatic suite.

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(1) Project funded under the Canada - Saskatchewan Subsidiary Agreement on Mineral Development 1984 - 89

(2) Economic Geology and Mineralogy Division, Geological Survey of Canada, Ottawa, Ontario

c) Greater Beaverlodge Area

High-grade Au-PGE mineralization from the Quartzite Ridge and the Missi showings was sampled for further detailed mineralogical studies. To date, no platinum minerals have been identified. The palladium minerals mertieite II, oosterboschite and gold containing up to 3.5 wt. percent Pd in solid solution have been identified and can account for the palladium present in the samples. Detailed proton microprobe analyses, with a lower limit of detection of 1 ppm for the platinum group elements, will be undertaken to test for solid solution of these elements in the associated phases: pitchblende, coffinite, vanadium-bearing mica, hematite, pyrite, marcasite, chalcopyrite, arsenopyrite, bornite, gold, electrum, clausthalite, cobaltite, gersdorffite, loellingite, guanajuatite, nevskite, tiemannite, mertieite II and oosterbosschite. In addition, two new unnamed selenides have been discovered (NiAsSe and CoAsSe) and will be examined for PGE solid solution.

2. Laboratory Investigations

The following laboratory investigations are in progress:

a) Geochronology

U-Pb, Mackenzie Diabase, Tremblay Lake:

Trace emounts of baddeleyite have been found and extracted from a Mackenzie diabase sill at Tremblay Lake. The U-Pb age for the baddeleyite was determined by L. Heaman of the Royal Ontario Museum to be 1265 ± 1 Ma.

Nd-Sm, Mafic Intrusions, Northern Saskatchewan:

A collaborative Nd-Sm and Rb-Sr isotopic study with the University of Saskatchewan has been undertaken in order to establish age and isotopic signature of the various intrusions in northern Saskatchewan. Table 2 is a list of intrusions studied, age determinations and the phases used to construct the associated isochron.

Table 2 - Nd-Sm Age Determinations of Mafic Intrusions

Intrusion	*Age (Ma)*	*Phases*[1]
Neyrinck Lake	1.81 ± .06	cpx, pl, ap
Logue Lake	1.86 ± .07	opx, pl, hbl, wr
Nemeiben	1.86 ± .04	opx, pl, cpx, wr
Wood Lake	1.71 ± .05	cpx, pl, hbl, wr
Clearwater Anorthosite	2.48 ± .03	opx, pl, wr
Dinty Lake	2.55 ± .23	opx, pl, cpx, wr

[1] wr, whole rock; hbl, hornblende; ap, apatite; cpx, clinopyroxene; opx, orthopyroxene; pl, plagioclase

b) Electron Microprobe Investigation of Silicate and Oxide Phase Chemistry

To date, approximately 1500 electron microprobe analyses have been conducted on silicate and oxide phases associated with the mafic-ultramafic intrusions in northern Saskatchewan. The large number of these analyses is a reflection of the degree to which fresh primary magmatic minerals are present in the investigated intrusions. Compositional data on magmatic assemblages is crucial to the understanding of the petrogenesis of these and related intrusions and their economic potential. Compositional data on metamorphosed portions of these intrusions enable the chemical changes associated with metamorphism to be defined, and given this knowledge, the economic potential of other metamorphosed mafic and ultramafic rocks in the province can be assessed. The following is a brief summary of the compositional data obtained from electron microprobe analyses since April 1, 1988. The data presented are the Mg number or Mg/(Mg+Fe) ratio of olivine (ol), orthopyroxene (opx), clinopyroxene (cpx) and the anorthite content of the feldspars (pl).

La Ronge Domain:

Gochager Lake: opx, 0.84 - 0.69; cpx, 0.88 - 0.79; ol, 0.72 - 0.67. The intercumulus feldspars have yet to be probed. The Ni content of the olivines is low, suggesting that they have been in equilibrium with a large quantity of nickeliferous sulphides during crystallization. Surface showings and diamond-drill hole intersections of Ni-Cu sulphides confirm this to be the case.

Fork Lakes: cpx, 0.87 - 0.88; ol, 0.81.

Neyrinck Lake: opx, 0.45 - 0.46; cpx, 0.59 - 0.66. The cumulus feldspars have yet to be probed.

Clam Lake: oxp, 0.77 -0.80; cpx, 0.79 - 0.81.

Reef Lake: ol, 0.83.

Nemeiben Lake: Due to the well-developed and unaltered nature of the ultramafic cumulate cyclic units in the layered series and the marginal zone of the complex, a 400 m stratigraphic section from the periphery towards the core of the intrusion was studied in considerable detail. Twenty-five investigated horizons of the layered series have the following compositional range: opx, 0.78 - 0.88; cpx, 0.84 - 0.90; ol, 0.78 - 0.86; pl, 0.43 - 0.77. Samples from the marginal zone show the following range: opx, 0.57 - 0.61; cpx, 0.61 - 0.67; pl, 0.42 - 0.56. The overall trend is for the Mg number of the mafic phases to increase from the marginal zone towards the interior of the intrusion, whereas the anorthite content of the intercumulus feldspar decreases. The nickel content of the olivines and the composition of chromite are geochemical parameters being evaluated as exploration tools.

Logue Lake: opx, 0.64 - 0.72; cpx, 0.68 - 0.75; pl, 0.38 - 0.48. This intrusion closely resembles that at Gochager Lake in the field; however, compositional data for the mafic phases demonstrates that the Logue Lake intrusion is more fractionated. This condition may be related to its lack of sulphides.

Peter Lake Domain:

Relict pyroxene and olivine have not been found in the Peter Lake Complex samples; however, plagioclase compositions and textures appear to be well preserved. Plagioclase core compositions from both medium-grained and pegmatitic gabbros are in the 0.57 - 0.59 range. The compositional range of these metamorphosed plagioclase-pyroxene cumulates contrasts strongly with that of metamorphosed plagioclase-pyroxene-apatite-sulphide cumulate at Ant Lake, 4.2 km west of Patterson Island on Reindeer Lake. The latter contains plagioclase with compositions in the 0.84 - 0.90 range. As the presence of abundant apatite would cause the anorthite content to be reduced from that found in an apatite-free environment, it is the more primitive anorthite-rich cumulates that should be sought as potential Cu-Ni-PGE hosts, rather than the more differentiated gabbroic cumulates.

Western Granulite Domain:

Clearwater Anorthosite Complex: Compositional ranges for the fresh magmatic pyroxenes, olivines and plagioclase minerals are as folows: opx, 0.42 - 0.79; cpx, 0.66 - 0.81; ol, 0.77; and pl, 0.38 - 0.68. Analyses of samples taken from an east-west traverse section between Fournier Lake and the Clearwater River confirm the earlier field observation that the cumulate layered sequence faces eastward (Hulbert, 1987). Electron microprobe analyses revealed that the eastern cumulates have the most evolved pyroxene and plagioclase compositions. Exploration for PGE should therefore concentrate on the earlier less evolved western portions of the layered sequence.

Mudjatik Domain:

Cup Lake: opx, 0.82; cpx, 0.87 - 0.92; ol, 0.80 - 0.86. In addition, magnetite containing up to 2.20 percent Cr_2O_3 was found to co-exist with an aluminous spinel containing between 58 and 62 percent Al_2O_3. High nickel contents in the olivines suggest that these thin ultramafic sills are poor potential hosts for Ni-Cu sulphide mineralization.

Glennie Lake Domain:

Wood Lake: opx, 0.66 - 0.81; cpx, 0.79 - 0.87; ol, 0.73 - 0.80; pl, 0.68 - 0.74 (cumulus), 0.37 - 0.45 (intercumulus). The nickel-depleted nature of the olivine suggests equilibration with significant quantities of Ni-Cu-Fe sulphides during its crystallization history.

Others:

Electron microprobe investigations of silicate and oxide phases from the Rottenstone Domain, the so-called "Noritic Series" north of Lake Athabasca and the Mackenzie diabase suite are in progress. In addition to the above mentioned analyses, amphiboles, micas, spinels and unknowns will be analyzed.

Proton microprobe analyses of certain metallic phases have also been carried out. It was found that chalcopyrite from the Rottenstone Lake deposit contains up to 44 ppm Ag in solid solution, whereas associated pentlandite can contain 8 to 20 ppm Ag. Also, pentlandite contains up to 20 ppm Pd in solid solution. However, in most cases the pentlandite, pyrrhotite and chalcopyrite contain < 1 ppm Os, Ir, Ru, Rh, Pt, Pd, Au, Bi and Te in solid solution.

c) Platinum Group Element Study of the Mackenzie Diabase Suite

Mackenzie diabase dyke and sill material from the Cree Lake area of northern Saskatchewan has been analyzed for major, trace and platinum-group elements. Thirty-one unmineralized diabase samples gave the following mean concentrations: Pd, 38 ppb; Pt, 6 ppb; and Au, 22 ppb.

Unmineralized Mackenzie diabase samples from other localities in northern Saskatchewan gave similar Pt and Pd values; however the Au values for those intrusions cutting the Athabasca Group are elevated by approximately three times. Although the Cree Lake diabases have no macroscopic sulphides present, they contain more than twice as much Cu as diabases from other localities examined in northern Saskatchewan. Their potential to host significant Cu-Ni-PGE-Au mineralization should not be underestimated. The contact between the sandstone and underlying basement could provide an excellent structural break for Mackenzie diabase magma to spread out laterally and form sill-like bodies with sulphide segregation deposits.

d) Geochemical Database

A geochemical database consisting of major, trace, platinum-group element and isotopic analyses for mineralized and unmineralized intrusions is being assembled.

3. References

Colborne, G.L. (1960): The geology of the Clut Lakes area (west half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 43, 28p.

________ (1962): The geology of the Wiley Lake area (east half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 69, 43p.

Hulbert, L. (1987): Investigation of mafic and ultramafic rocks, and platinum group element mineralization in northern Saskatchewan: preliminary findings; *in* Summary of Investigations 1987, Sask. Geol. Surv., p125-130.

Kranck, S.H. (1955): Geology of the Stony Rapids norite area, Northern Saskatchewan; unpubl. M.Sc. thesis, McGill Univ., 64p.

Other Northern Studies

Kinematic Investigation of Part of the Needle Falls Shear Zone[1]

M.R. Stauffer[2] *and J.F. Lewry*[3]

Stauffer, M.R. and Lewry, J.F. (1988): Kinematic investigation of part of the Needle Falls Shear Zone; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

The Needle Falls – Parker Lake Shear Zone, located in northern Saskatchewan, is a major Early Proterozoic crustal discontinuity within the western part of the Trans-Hudson Orogen. Throughout its exposed strike length of almost 400 km, it defines the western-northwestern margin of the ca. 1.85 Ga Wathaman Batholith. It is also the junction between reworked Archean continental crust and infolded Early Proterozoic miogeoclinal metasediments (Wollaston Group) of the Cree Lake Zone and Peter Lake Domain lying to the northwest and the predominantly juvenile Early Proterozoic arc terrains of the Reindeer Zone to the southeast. Neither sense nor amount of displacement along this regionally significant ductile shear zone have hitherto been adequately documented. We here report preliminary results of detailed kinematic investigation of a well-exposed southern part of the shear zone in the vicinity of Needle Falls on the Churchill River, an area previously mapped by Money (1965) and Munday (1978).

In the study area (Figure 1a), protomylonitic to ultramylonitic gneisses (cf. Wise et al., 1984) of the Needle Falls Shear Zone form a subvertical north-northeast-striking belt over 1 km wide. Within this belt, mylonites and ultramylonites displaying dominant 'C' plane (shear foliation) fabrics occur over a width of about 500 m. Mylonite protoliths include megacrystic to nonmegacrystic monzogranite-granodiorite, as well as xenolithic amphibolite-hornblende gneiss screens and later aplite-pegmatite sheets of the Wathaman Batholith, and also augened (megacrystic) granitic gneisses representing Archean basement of the Cree Lake Zone.

1. Relations East of the Shear Zone

Potassium feldspar megacrystic monzogranite and granodiorite of the 'main phase' of the Wathaman Batholith (Fumerton et al., 1984) occur in a 1 to 2 km wide belt east of the shear zone. These are variably intruded by leucogranite, aplite and pegmatite sheets ranging from a few centimetres to tens of metres in thickness. Amphibolites, hornblende gneisses and less common psammitic gneisses occur irregularly as subequant to tabular, angular to rounded xenoliths ranging from several centimetres across to major screens tens of metres long and several metres wide. Leucogranite-aplite-pegmatite sheets and xenolithic screens are commonly subparallel, defining a crude layering (S_0) which may be related to primary magmatic flow within the batholith. Farther east, the Wathaman Batholith grades irregularly into older agmatitic, schlieric and nebulitic granodiorites, tonalites and trondhjemites of the Rottenstone Tonalite-Migmatite Belt across a complex marginal metasomatic and injection aureole. Previous work (Lewry and Slimmon, 1985) shows that the older gneisses are complexly intruded by generally massive to weakly foliated megacrystic and nonmegacrystic granite bodies coeval with the Wathaman Batholith throughout this part of the Rottenstone Domain: Wathaman-related granite sheets postdate at least two deformational phases affecting older rocks.

Outside the shear zone, rocks of the Wathaman Batholith have a weak to moderately well developed tectonic foliation (S_1) variably subparallel or oblique to S_0 banding. Detailed fabric features suggest that this foliation is predominantly a flattening fabric. Locally, S_1 is axial planar to coeval, open to tight F_1 folds defined by S_0 banding. A prominent S_0/S_1 intersection lineation (L_1), coaxial with fold hinge lines, is widely developed. In the eastern part of the study area, S_0 and S_1 generally strike between 040 and 055° and dip moderately to steeply to the southeast. Towards the shear zone, however, both swing progressively towards 025 to 030° and become subvertical (Figure 1b). F_1 fold hinge lines and L_1 lineation generally plunge at 20 to 30° to the southwest but become more gently south-plunging towards the shear zone (Figure 1b). Field observations and structural geometry suggest that the structures described above predate, and are kinematically unrelated to, the shear zone itself.

2. Relations West of the Shear Zone

One lakeshore outcrop, situated southwest of Needle Falls and about 100 m west of ultramylonites of the shear zone, comprises coarse-grained unfoliated metagabbro/metapyroxenite net-veined by leucogranite which is apparently weakly deformed. However, most of the limited outcrops immediately west of the shear zone are coarsely megacrystic to strongly augened granitic gneisses locally injected by thin aplite or pegmatite veins and contain few xenoliths. Although where least deformed these are superficially similar to the main phase Wathaman monzogranite, both previous work and observed relationships to metasediments of the Wollaston Group indicate that they represent Archean basement.

Contact between augen gneisses and Wollaston Group metaconglomerates was noted in one outcrop 200 m west of Needle Falls. The metaconglomerates contain

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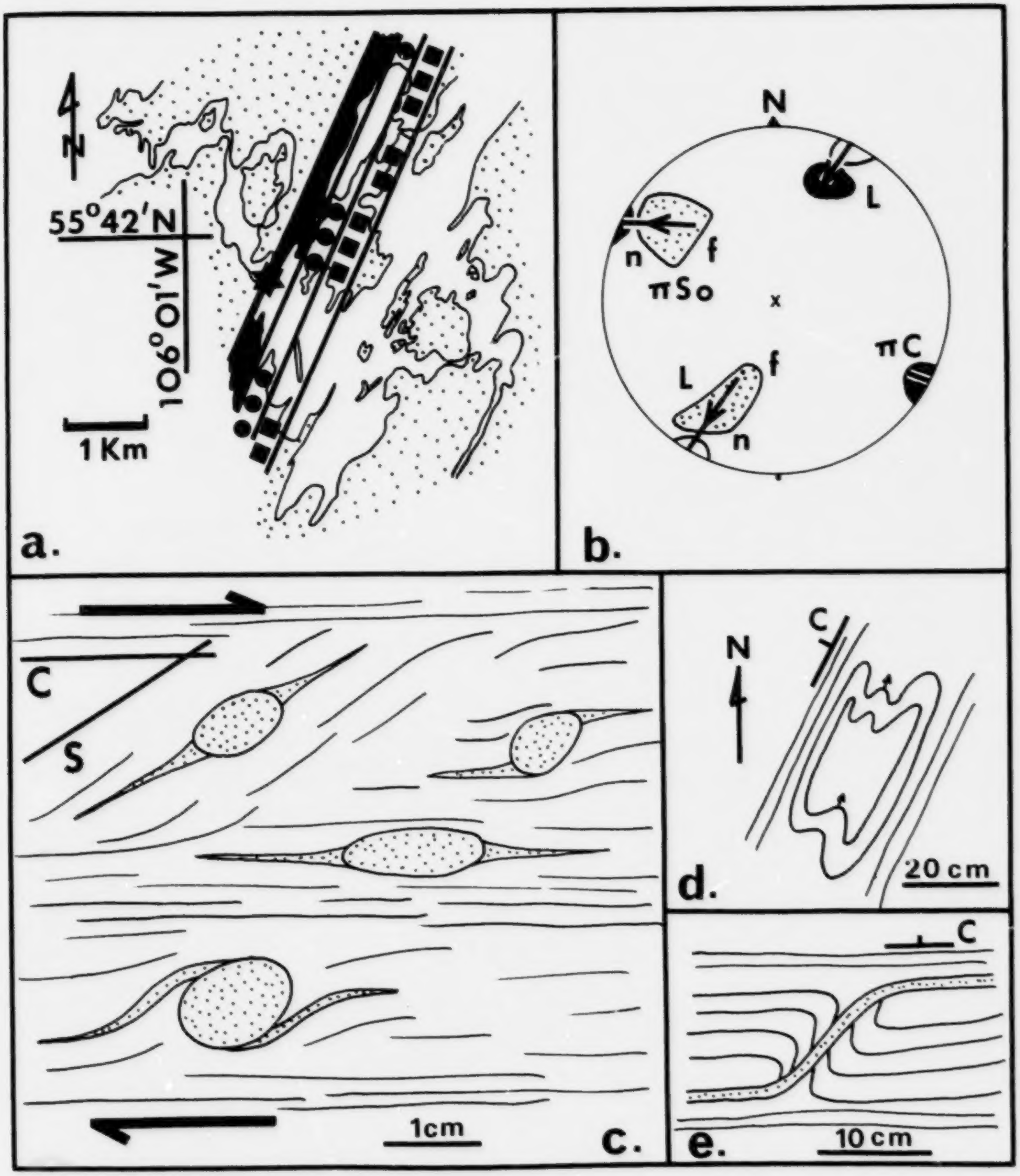

Figure 1 – a) Generalized map of the Needle Falls Shear Zone (NFSZ) in the study area. Wathaman Batholith lies to the east and Wollaston Domain of the Cree Lake Zone to the west; star shows location of Needle Falls. Solid black, ultramylonite; large dots, mylonite; large squares, protomylonite. b) Stereographic plot showing rotation of F_1/L_1 lineation into shear zone stretching direction L_m (all lineations designated L in diagram) and S_0 into C_m (designated C in diagram) in the shear zone. For 'L': dotted field (south-plunging) shows range of data (9) for Wathaman Batholith east of protomylonite, outside NFSZ; 'n' indicates data close to NFSZ (within 1 km); 'f' indicates data further away. Open field shows range of data (4) for protomylonite and mylonite. Solid field shows range of data (9) for ultramylonite. For $\pi S_0 - \pi C_m$: dotted field shows range of data (15) for Wathaman Batholith east of protomylonite; 'n' indicates data within 1 km of NFSZ; 'f' indicates data farther away. Solid field shows range of data (16) within the NFSZ. c) Diagrammatic illustration of major porphyroclast/tail and C/S relationships in the protomylonite and mylonite which indicate dextral movement during ductile shear strain; top of diagram is to the west. d) Sheath fold in mylonitic layering. e) Late-stage brittle-ductile compressional shear band (dotted) and folded C_m.

rounded pebble- to cobble-sized quartz and K-feldspar clasts in a gritty feldspathic quartzite matrix, consistent with local derivation from rocks similar to the adjacent augen granite gneiss. The contact is tectonically modified and an unconformity cannot be unequivocally documented.

Protomylonitic augen gneisses derived from Archean basement protoliths are well exposed at the west end of the portage south of Needle Falls. To the east, along the portage, there is a high strain gradient to mylonite and ultramylonite, clearly derived from the same protolith, over a distance of 40 m.

Granitic basement gneisses, metaconglomerates and orthoquartzites of the Wollaston Group have a strong to intense and steeply west-dipping tectonic foliation striking 020 to 035°, subparallel to that of the shear zone. A prominent stretching lineation, plunging to the north-northeast at about 30°, is defined by elongation of dynamically recrystallized feldspar augen in the basement gneisses, pebble elongation in the metaconglomerates, and by rodding and pressure shadow tails around small pebbles in orthoquartzites. Strain gradation into mylonitic derivatives of the gneisses is marked by matrix grain-size reduction, increased flattening and elongation of dynamically recrystallized potassium feldspar megacrysts and general intensification of both planar and linear fabric elements with little significant change in attitude. In contrast to mylonitic derivatives of the Wathaman Batholith, described below, rotated tailed porphyroclasts are not developed and there is little other clear indication of rotational strain.

3. Kinematic Features of the Shear Zone

Westward strain gradation to protomylonitic gneisses of the shear zone from rocks of the Wathaman Batholith is accompanied by regional rotation and steepening of S_0 and S_1 planar fabrics towards parallelism with the shear zone margins. In the outer margins of the shear zone, 'premylonitic' to protomylonitic gneisses generally show little mesoscopic indication of consistent sense of rotational strain, and the foliation is provisionally interpreted as a predominantly 'S' (flattening) fabric. Possible 'C' (shear) plane development related to the shear zone is evident only locally. Passage into inner parts of the protomylonite subzone is, however, marked by a prominent decrease in matrix grain size, increasing incidence of rotational fabric features such as rotated potassium feldspar porphyroclasts with dynamic recrystallization tails, and increasingly clear development of kinematically related 'C' (shear) and oblique 'S' (flattening) foliations.

Strain gradation to fine-grained mylonite and ultramylonite subzones is marked by the relatively abrupt development of an intense subvertical to steeply west-dipping kinematic foliation and a mylonitic lamination parallel to, and in part defined by, transposed S_0 banding which strikes consistently at about 025 to 030°. A variety of attendant features, including development of asymmetric, rotated and tailed porphyroclasts as well as kinematically related oblique 'S' planes (flattening fabric), designated Sm, indicate that this dominant mylonitic foliation is a 'C' plane (shear plane) fabric, designated C_m. Well-developed oblique C_m-parallel S_0 and coeval S_m planar fabrics were observed in several outcrops in the protomylonite-mylonite transition zone; in the ultramylonite subzone, there is transition to a general C_m-parallel S_m-parallel S_0 planar fabric.

Throughout the mylonite-ultramylonite subzones, a pronounced penetrative lineation (L_m) plunges to the north-northeast at about 25°. This fabric element is defined by the preferred orientation of finite elongation axes (X-direction) of triaxially deformed porphyroclasts and general mineral streaking, together with rodding and apparent S_0/C_m intersection lineation. The L_m lineation is also commonly parallel to hinge lines of tight to isoclinal intrafolial folds, defined by S_0 layering and axial planar to C_m, and in a few outcrops is paralleled by hinge lines of closed sheath folds (Figure 1d). This fabric element is interpreted as a stretching lineation coeval with the main phase of ductile shear strain and thus indicates slightly oblique transcurrent displacement across the shear zone.

Kinematic sense-of-movement indicators related to the main phase of ductile shear strain (Figure 1c) tend to be best developed in transitional protomylonitic-mylonitic parts of the shear zone, and include:

1) Angular relation of oblique C–S planar fabrics (Simpson and Schmid, 1983).

2) Dynamically recrystallized and rotated K-feldspar porphyroclasts (Passchier and Simpson, 1986). These include types with symmetrical dynamic recrystallization tails elongated in either S_m or C_m, highly asymmetric σ-type porphyroclasts with tails elongate in C_m and highly rotated δ-type porphyroclasts with curving 'winged' tails. The last-mentioned provide the most convincing evidence of sense of movement.

Given documented orientation of the stretching lineation (L_m), such features consistently and unequivocally indicate oblique dextral shear sense, with a subordinate east-side-up vertical displacement component.

Varied small-scale features, developed mainly within the mylonitic and ultramylonitic subzones, attest to continued brittle-ductile to late brittle movement along the shear zone subsequent to development of the ductile strain fabrics described above. These include:

1) Steeply plunging small-scale asymmetric folds, deforming S_0/C_m mylonitic banding, generating from brittle-plastic *décollements* parallel to the latter. Fold vergence indicates predominant dextral movement sense, but conjugate structures and 'back-fold pile-ups' occur locally in some fold bands.

2) Brittle-ductile to brittle compressional shear bands and listric thrusts (Figure 1e), generally rooting in *décollements* and thin zones of cataclasis parallel to prior S_0/C_m mylonitic banding. These are commonly, though not exclusively, associated with overturned limbs of small-scale asymmetric folds and

most show dextral movement sense, although subordinate conjugate thrusts with sinistral displacement occur locally.

3) Extensional shear bands displacing S_0/C_m, again indicating overall dextral movement sense.

4) Asymmetric boudinage of more competent felsic mylonite layers, showing clockwise rotation of boudins between oblique sinistral extensional shear bands. Geometry and sense of movement in such zones is consistent with overall dextral shear (cf. Simpson and Schmid, 1983).

5) A variety of straight, sigmoidal or highly folded and boudinaged quartz-filled tension gashes, apparently developed at different stages in the kinematic history of the shear zone. Some are developed in late brittle breccia zones. Others occur in overturned limbs of north-verging late asymmetric folds; relations seen in a few outcrops suggest that most of the latter were initially developed normal to the principal extension direction during dextral shear and were rotated into their present attitude during progressive brittle-ductile shear strain.

6) Very late small-scale brittle fractures, including both conjugate thrust sets oblique to and offsetting mylonitic layering, and other sets almost normal to mylonitic layering.

7) Thin pseudotachylite veins within late cataclastic breccia zones and locally cross-cutting mylonitic banding in the walls of such zones.

The orientation and character of most of these structures thus indicates continuation of dominantly transcurrent dextral movement throughout brittle-ductile to brittle stages of shear zone development.

4. Preliminary Interpretation of Geometric Relationships

Given unequivocal evidence of dextral displacement during all documented stages of development of the

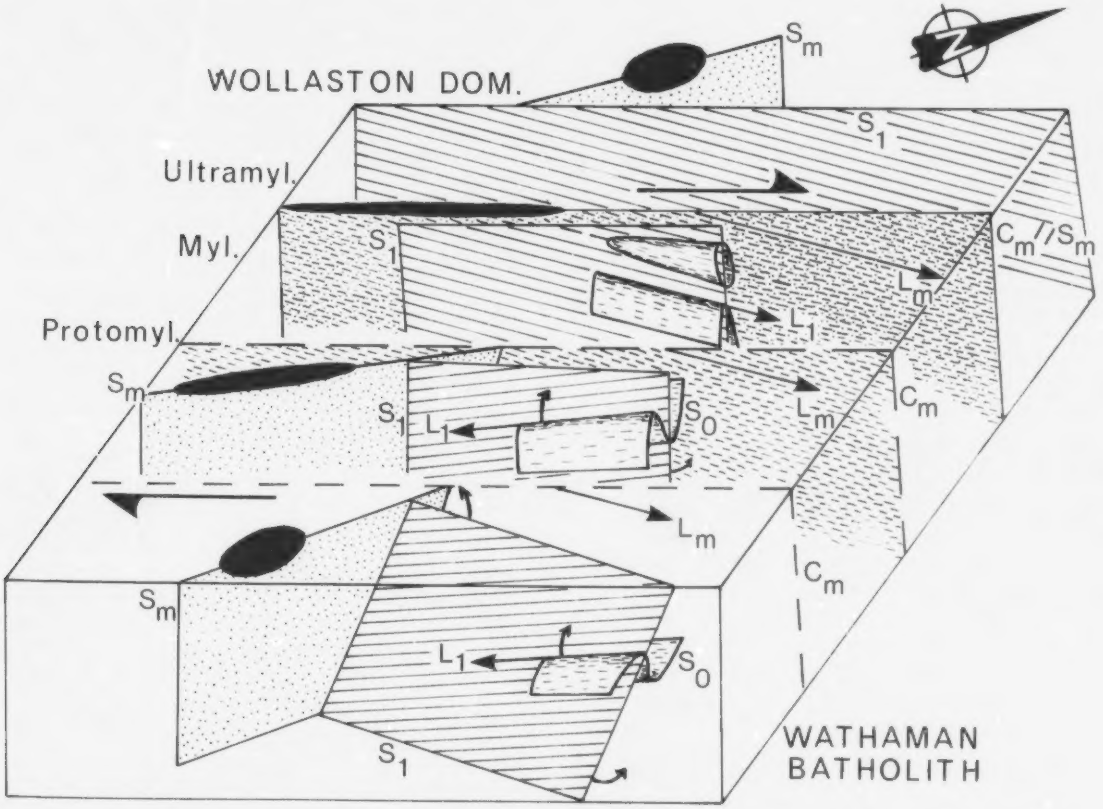

Figure 2 - Diagrammatic representation of geometric relations, rotation and development of planar and linear structures in the Needle Falls Shear Zone. Horizontal sections through finite strain ellipsoids shown schematically as solid black ellipses. S_0 is primary layering in Wathaman Batholith; S_1 is pre-shear zone tectonic foliation in Wathaman Batholith and Wollaston Domain (probably not of the same age). S_m is flattening plane related to shear zone strain. C_m is shear plane fabric related to shear zone strain. L_1 is pre-shear zone lineation and fold hinge lines in the Wathaman Batholith. L_m is stretching direction related to shear zone strain.

Needle Falls Shear Zone, the geometric and age relationships of planar and linear fabric components external to and within the zone are provisionally interpreted as follows (Figure 2):

1) S_0 and S_1 in rocks of the Wathaman Batholith to the east of the Needle Falls Shear Zone predate main ductile movement along the shear zone.

2) Towards the shear zone, S_0 and S_1 were both initially rotated towards the incipient C_m plane by dominant pure shear flattening rather than by simple shear rotation – that is, they were rotated towards the flattening plane of the progressive strain ellipsoid, which in the outer margins of the shear zone would be oblique to shear zone margins. Before reaching the flattening plane, however, they rotated into the 'C' (slip) direction, at which point a strong C_m fabric typifying the mylonite-ultramylonite subzones developed subparallel to transposed S_0/S_1. It seems likely that both S_0 and S_1 may have acted as slip surfaces during this process. This interpretation explains the apparently anomalous sense of rotation of early planar structures, which might otherwise be taken as evidence for sinistral, rather than dextral, displacement.

3) Initially southwest-plunging F_1 fold hinge lines and L_1 intersection lineation were also progressively rotated and eventually transposed into the northeast-plunging L_m stretching direction. Local flow surges within the ultramylonites, oblique to F_1 fold hinge lines, produced sheath folds.

5. Magnitude of Displacement

No realistic estimate of total displacement across the shear zone is possible on the basis of available data. However, various indirect indicators, including known length of the Needle Falls – Parker Lake zone, widths of protomylonite, mylonite and ultramylonite belts within the shear zone, and preliminary shape fabric analysis of deformed porphyroclasts in various parts of the shear zone, suggest a possible minimum horizontal displacement on the order of 40 to 50 km. True displacement is likely to be considerably greater than this.

6. References

Fumerton, S.L., Stauffer, M. R. and Lewry, J.F. (1984): The Wathaman Batholith: largest known Precambrian pluton; Can. J. Earth Sci., v21, p1092-1097.

Lewry, J.F. and Slimmon, W.L. (1985): Compilation bedrock geology, Lac la Ronge, NTS area 73P/73I; Sask. Energy Mines, Rep. 225 (1:250,000 scale map with marginal notes).

Passchier, C.W. and Simpson, C. (1986): Porphyroclast systems as kinematic indicators; J. Struct. Geol., v8, p831-843.

Simpson, C. and Schmid, S.M. (1983): An evaluation of criteria to deduce the sense of movement in sheared rocks; Geol. Soc. Am. Bull., v94, p1281-1288.

Money, P.L. (1965): The geology of the area around Needle Falls, Churchill River, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 88, 70p.

Munday, R.J.C. (1978): The shield geology of the Île-à-la-Crosse (east) area, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 189, 27p.

Wise, D.U., Dunn, D.E. Engelder, J.T., Geiser, P.A., Hatcher, R.D., Kish, S.A., Odom, A.L. and Schamel, S. (1984): Fault-related rocks: suggestions for terminology; Geology, v12, p391-394.

The Origin of the Frontier Granite, Goldfields Area, Saskatchewan: A Metasomatic Assessment

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Appleyard, E.C. (1988): The origin of the Frontier granite, Goldfields area, Saskatchewan: a metasomatic assessment; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

Gold was discovered in the Goldfields area on the north shore of Lake Athabasca prior to World War II and, since then, exploration has been reattracted to the region with the rise in gold prices. The focus of most of the interest has been on three pyritic granite bodies, collectively referred to as the "mine" granites, with which the gold has very strong spatial restrictions. These "mine" granites have, in turn, been the subject of controversy respecting their mode of origin, specifically whether they are magmatic or the products of granitization. The source of the gold, and hence the controls on its emplacement, are ancilliary and dependent areas of speculation.

The present study comprises an interpretation of lithogeochemical data from the Frontier granite (one of the three "mine" granites) and its host rocks, with the objective of establishing whether a metasomatic origin is a permissible and defensible hypothesis and, if so, what physical and chemcial constraints would apply to such a model.

1. Setting and Description

The following description of the Frontier granite in its field setting is derived from the summary by Sibbald and Jiricka (1986). A description of the general geology of the Goldfields area can be found in Sibbald (1984).

The Frontier granite comprises lenticular sheets of leucocratic granitic-looking rock marked by appreciable disseminated pyrite and hosted by sericitic quartzites which are part of the Lower Proterozoic supracrustal series of the area. Granularity (Barker, 1983) is "fine" (i.e., approximately 0.5 mm), the granite is widely and intensively veined with quartz and it contains almost no albite (Na/K=0.08, molar prop.). Undulose extinction in quartz grains and bent and fractured feldspars and micas are textural indications that the "mine" granites were subject to strain during the second of two locally recognized episodes of deformation. These effects are least marked in the Frontier.

In general, quartz veins in the "mine" granites are mineralized with both gold and sulphides, including pyrite, sphalerite and chalcopyrite. Tourmaline, chlorite and hematite are also recorded. Sibbald and Jiricka (1986) report that the vein mineralization is geochemically simple and expressed by Au ± Ag, Zn, Pb, Cu and Mo. No marginal alteration of the host rock is apparent, although retrograde mineral changes may occur there. Veins appear to be dilational "gash" type and range in scale from microscopic to many metres in length.

Geochemically, the Frontier granite is strongly inhomogenous with high intersample variances for most elements (Table 1). This heterogeneity, plus transitional contacts with the hosting quartzites and quartz-feldspar blastic textures, are observations that have been used to support a metasomatic origin.

2. Geochemical Data and Data Handling

a) Primary Data

Thirty-six whole rock and trace element analyses were available for study. These had previously formed the basis of a similar metasomatic study by Quirt and Rees (1987) and had been subdivided into three facies by Quirt (1987) as follows:

1) **Quartzite** (18 samples) - Strong evidence for sedimentary origin (e.g., bedding, sedimentary layering, pebble horizons, etc). No quartz veining and little or no pyrite.

2) **Transitional** (10 samples) - Some bedding and sedimentary layering evident as well as the occurrence of massive material corresponding to a distinct reddening with respect to the adjacent quartzite.

3) **"Granite"** (8 samples) - Massive, reddish rock without evidence for sedimentary structures. Generally veined with quartz and often pyritic.

SiO_2 was not analysed but rather determined by difference; as a result, it has not been included in the present study. Specific gravity values for all samples were available.

Data for some elements, specifically C, Be, Se, Mo, Ag, Cd, Eu, Tb and Lu, are of poor quality inasmuch as many of the measured values fall at or near the minimum detectable level. No significance is therefore attached to the data of these elements in the following interpretations.

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Table 1 – Average analyses of four categories of Frontier granite and its protoliths. Quartzite^R represents the original 'raw' analyses of the host quartzites and Quartzite^{CI} represents the same analyses recalculated to a constant average amount of the immobile elements Ti, P, V, Y, Zr, La, Ce, Dy and Yb. Numbers in brackets indicate the number of samples in each mean. Average analyses are given for 'net compositons' of specimens in the 'transitional' and 'granite' groups (3 and 4). All data are expressed in moles/100 cc for major elements (Ti to S) and as moles/m^3 for trace elements (Li to U). The value listed as the mean ($\bar{x}$) is the arithmetic mean for all major elements and the logarithmic mean value for trace elements. The values are expressed in scientific notation, the mantissa being followed by its exponent indicating the number of places to the right (+) or to the left (–) that the decimal point should be moved. The mean value for each element is accompanied by its coefficient of variation, c. This statistic is equal to the mean, $\bar{x}$, divided by the standard deviation, s.d., for major elements. For trace elements c = (antilog ($\bar{x}$ + s.d.) – antilog ($\bar{x}$ – s.d.))/ (2 × antilog ($\bar{x}$)). An asterisk after an element indicates that data are of poor quality due to the inclusion of many values at or near minimum detectable levels.

	Quartzite^R (18)			Quartzite^{CI} (18)			Transitional (10)			"Granite" (8)		
	$\bar{x}$		'c'	$\bar{x}$		'c'	$\bar{x}$		'c'	$\bar{x}$		'c'
S.G.	2.655		0.015	2.655		0.015	2.659		0.011	2.628		0.004
Ti	6.07	-03	0.66	5.92	-03	0.28	9.25	-03	0.78	3.93	-03	0.37
Al	6.46	-01	0.37	7.39	-01	0.42	9.37	-01	0.32	1.09	00	0.36
Fe^{3+}	5.60	-02	0.75	5.98	-02	0.63	9.96	-02	0.54	7.12	-02	0.48
Fe^{2+}	2.40	-02	0.52	3.29	-02	0.81	5.84	-02	0.57	5.03	-02	0.54
ΣFe^{2+}	8.00	-02	0.62	9.26	-02	0.63	1.58	-01	0.53	1.22	-01	0.48
Mn	8.95	-04	1.63	1.02	-03	1.48	5.79	-04	0.74	2.95	-04	0.67
Mg	8.45	-02	0.96	9.21	-02	0.83	9.71	-02	0.84	4.30	-02	1.02
Ca	4.98	-03	0.63	6.50	-03	0.67	8.93	-03	0.57	9.71	-03	0.71
Na	3.15	-02	0.29	3.97	-02	0.60	5.16	-02	0.45	6.74	-02	0.37
K	4.24	-01	0.44	5.06	-01	0.61	5.87	-01	0.48	8.86	-01	0.32
P	2.49	-03	0.67	3.04	-03	0.64	4.21	-03	0.76	2.54	-03	0.27
C*	6.37	-03	0.22	8.41	-03	0.65	1.63	-02	0.53	1.51	-02	0.33
S	3.10	-04	0.64	3.61	-04	0.73	3.74	-04	1.01	8.41	-03	1.16
Li	6.01	00	0.85	6.73	00	0.87	6.35	00	0.91	3.86	00	1.01
Be*	4.10	-01	0.59	4.59	-01	0.50	4.90	-01	0.38	7.00	-01	0.35
B	6.48	00	1.22	7.26	00	0.96	5.41	00	1.24	1.19	+01	0.89
V	1.04	00	0.74	1.17	00	0.59	1.64	00	0.54	1.25	00	0.77
Cr	8.08	00	0.52	9.05	00	1.11	1.36	+01	0.67	1.74	+01	1.26
Co	2.40	-01	0.66	2.69	-01	0.51	2.67	-01	0.63	3.13	-01	0.54
Ni	4.69	-01	0.48	5.25	-01	0.62	1.45	00	0.59	6.39	-01	1.26
Cu	2.67	-01	0.64	2.99	-01	1.24	2.25	-01	1.07	6.85	-01	0.60
Zn	5.27	-01	1.12	5.90	-01	0.87	4.73	-01	0.64	4.69	-01	0.60
As	8.65	-02	1.16	9.70	-02	1.51	4.51	-01	1.16	2.70	-01	1.61
Se*	4.68	-03	0.41	5.24	-03	0.62	4.87	-03	0.42	1.54	-02	0.43
Rb	5.53	00	0.48	6.20	00	0.47	8.19	00	0.45	1.26	+01	0.32
Sr	1.03	00	0.35	1.15	00	0.70	1.67	00	0.56	2.56	00	0.48
Y	2.81	-01	0.70	3.14	-01	0.42	2.92	-01	0.10	2.69	-01	0.17
Zr	3.82	00	0.60	4.28	00	0.27	5.28	00	0.35	5.66	00	0.30
Mo*	1.70	-01	0.40	1.91	-01	0.56	2.46	-01	0.52	3.37	-01	0.32
Ag*	5.52	-03	0.51	6.19	-03	0.96	7.13	-03	0.42	1.17	-02	0.35
Cd*	3.11	-02	0.43	3.49	-02	0.73	5.56	-02	0.49	6.12	-02	0.43
Ba	2.03	+01	0.37	2.28	+01	0.88	3.22	+01	0.46	3.34	+01	1.20
La	5.41	-01	0.80	6.06	-01	0.45	6.09	-01	0.64	7.24	-01	0.25
Ce	1.14	00	0.73	1.28	00	0.38	1.41	00	0.52	1.58	00	0.19
Nd	3.50	-01	1.07	3.92	-01	0.67	4.46	-01	0.97	2.37	-01	1.16
Eu*	1.34	-02	0.46	1.50	-02	0.36	1.81	-02	0.40	2.40	-02	0.26
Tb*	4.21	-02	0.43	4.71	-02	0.67	6.99	-02	0.67	7.94	-02	0.35
Dy	2.74	-02	0.73	3.07	-02	0.42	2.42	-02	0.51	4.56	-02	0.36
Er	2.13	-02	1.04	2.39	-02	1.39	2.88	-02	0.87	2.29	-02	0.70
Yb	1.99	-02	0.62	2.23	-02	0.24	2.82	-02	0.21	1.58	-02	0.49
Lu*	8.38	-03	0.23	9.40	-03	0.54	1.20	-02	0.38	1.80	-02	0.35
Au	8.16	-05	0.97	9.15	-05	1.38	2.00	-04	1.15	2.00	-03	3.75
Pb	2.54	-01	0.51	2.84	-01	0.61	4.20	-01	2.80	4.81	-01	0.34
Th	1.60	-01	0.77	1.79	-01	0.53	1.83	-01	0.48	1.86	-01	0.98
U	2.80	-02	0.94	2.76	-02	0.38	3.16	-02	0.39	4.73	-02	1.24

b) Gresens Calculations

The metasomatic assessment of these rocks has been undertaken utilizing Gresens (1967) general metasomatic equation. Descriptions of the procedures involved have been described previously (Babcock, 1973; Taylor and Appleyard, 1983; Binns and Appleyard, 1986) and need not be repeated here except to recall that absolute fluxes (gains, losses and immobilities) are calculated using corrections for density and volume changes which occurred during the metasomatic event (and any superimposed volume- or composition-altering events). The volume change parameters are determined for each altered sample by a process which normalizes the mean values for a suite of immobile elements (i.e., those that were neither gained nor lost). The immobile character of these important elements is established by a pattern-recognizing procedure based on a derivative of Gresens equation. In other words, the procedure does not involve the making of constraining assumptions for the operative volume change factors nor of the identity of the immobile elements.

c) Identification of Immobile Elements

Clustering patterns of *zero change volume factors* (FV values; see Appendix in Taylor and Appleyard, 1983) indicate that nine elements have characteristics that identify them as behaving in an immobile manner in the present suite. These elements are Ti, P, V, Y, Zr, La, Ce, Dy and Yb. Because of the high initial variances in the host quartzites, not all of the elements *appear* immobile in every altered rock. The number (out of a total of 18) of **transitional** and **"granite"** samples showing immobility has been identified for each element, as follows: Y 17, La 16, Zr 15, Ce 14, Ti 13, P 11, Dy 1, Yb 11 and V 7. These elements have been used to calculate the volume change factors for each altered rock with respect to the unaltered rock whose relative volume is taken as 1.00. The identification of these elements as being immobile during the formation of these rocks is the first conclusion drawn from this metasomatic assessment.

d) Heterogeneity of Quartzite

The quartzites that host the Frontier granite comprise a variable suite of orthoquartzites, arkoses and crystalloblastic derivatives of argillaceous sandstones; their high to very high geochemical variances are listed in Table 1. Metasomatic fluxes have to be established with respect to the composition of an unaltered parent or host rock, taking into account changes in density and in the mean immobile element levels. Where parent rocks are highly variable, the composition of the actual parent from which a particular altered rock has been derived will usually be in doubt. The relatively large number of parental **quartzite** analyses in the present data set, however, permits the use of the *mean* **quartzite** analysis as the "model parent" from which all the altered rocks are assumed to have been derived. The possible error in making this assumption can be judged from the scatter of the quartzite analyses on the metasomatic variation diagrams (Figure 1).

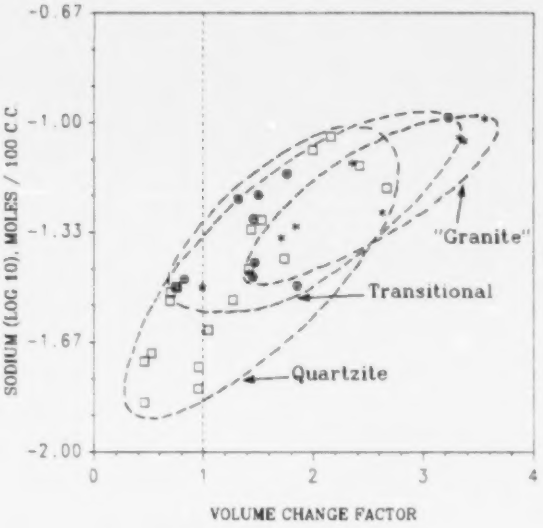

Figure 1 – Plot of sodium contents of all samples versus volume change factors. Quartzite analyses are normalized to constant average immobile elements. Sodium concentrations are expressed as log conversions of the molar value after 100 cc of the protolith was latered. Symbols are as follows: □ = quartzite, ☆ = model parent quartzite, Φ = transitional rocks, ✱ = "granite".

Mineralogical variations in the host **quartzites** can be regarded as involving a quartz and feldspar versus "other" minerals dichotomy. All the elements identified as being immobile would be primarily resident within these "other" minerals rather than in the quartz-feldspar framework. If the **quartzite** analyses are normalized to constant average immobile element contents, they can be arranged in a sequence from lower to higher quartz + feldspar contents than the "model parent" quartzite. This device also results in each **quartzite** having an *apparent* volume change factor with respect to the "model parent". Thus the **quartzite** analyses can be plotted on a metasomatic variation diagram with the **transitional** and **"granite"** samples and the variances inherent within each of the three groups will be portrayed in extensively overlapping fields (Figure 1). The mean of these recalculated **quartzite** analyses is listed Table 1.

e) Density, Volume and Mass Change Factors

Compositional changes in rocks typically result in corresponding changes in rock densities. This is readily established by comparing densities of unaltered rocks and their alteration products. Alteration also typically results in changes in rock volume. This may be less immediately obvious, due to the usual lack of any standard to refer volume changes against, but the cavernous texture of highly leached gossan or the dilated structure of a net-veined stockwork rock are examples that require little imagination to perceive the volume changes. As noted above, volume changes can be quantified using the Gresens general metasomatic equation which incorporates a volume change factor, FV. Inasmuch as the product of density and volume parameters is the rock mass, so the product of density and volume change parameters gives the *mass change* factor for the altered rock with respect to the unaltered parent. In the present study these *change* parameters are always referenced to the density, volume and mass of arbitrary volumes of the "model parent" **quartzite**.

Variances in density measurements of the quartzite hosting the Frontier granite are very small as the coefficient of variance listed in Table 1 indicates, although the range is from 2.605 to 2.790. **Transitional** specimens have a range from 2.627 to 2.710 and a smaller coefficient of variation than the **quartzites** (Table 1), while the **"granite"** range is from 2.616 to 2.644 with a commensurately smaller coefficient of variation. The density change ratios for the **transitional** and **"granite"** groups are listed in Table 2.

Volume change ratios, assuming arbitrary initial volumes of 100 cc and 1 m^3 for major and trace elements respectively, are calculated using the immobile elements as a normalization standard. Table 2 illustrates that the **transitional** samples display a mean volume increase of 57 percent over the "model parent" and, on the same basis, the **"granite"** group of specimens has a mean volume increase of 153 percent. Since the density change ratios are so close to 1.000, the mass change ratios are virtually the same as the volume change ratios. Taking all the altered rocks as a single group, the mean mass increase is 98 percent (ratio = 1.98), corresponding to a mean volume increase of 100 percent (ratio = 2.00).

The second conclusion that can be reached in the metasomatic assessment is that the immobile elements indicate an approximate doubling of the mass and volume of the Frontier granite with respect to the host quartzites.

3. Net Compositions of the Frontier Granite

Once density and volume change ratios have been determined, Gresens equations for the altered rocks can be solved for changes in mass (i.e., the fluxes) of all the constituent elements. Fluxes can be expressed as positive gains or negative losses as appropriate. An alternative way of expressing the altered rock composition is to arithmetically sum the gain and loss values with the composition of the "model parent". This procedure produces a net composition that resembles the raw analysis but is not required to sum to 100.0. The net composition represents the amounts of every element remaining in a sample after the starting quantity of the parent rock has been altered. The starting volumes were defined previously; abundances of the elements are given in moles.

Table 2 – Density, Volume and Mass Change Parameters Derived for the Granitization Model of the Frontier Granite

	Transitional		*"granite"*	
	Mean	*Range*	*Mean*	*Range*
Density Change Ratio	1.002	0.989 – 1.021	0.990	0.985 – 0.996
Volume Change Ratio	1.571	0.761 – 3.24	2.526	1.42 – 3.56
Mass Change Ratio	1.571	0.757 – 3.20	2.499	1.41 – 3.53

Mean net elemental abundances for the **transitional** and **"granite"** groups are listed in Table 1. Many elements, although not all, show a progressive reduction in the coefficients of variation from the **quarzite** to the **"granite"**, indicating that the rock becomes more homogenous in this direction, a deduction that accords with field and petrographic observations.

4. Results

a) Index of Granitization

For rock analyses to be plotted on graphs to illustrate trends of geochemical fluxes, they must be sorted into a sequence from unaltered or least altered to most altered. This means defining a parameter that represents the intensity of the process. In this study, the parameter that appears to change most progressively throughout the transition from **quartzite** to **"granite"** is the volume change factor (Table 2). This factor (FV) has therefore been adopted as an *index* of the granitization process, and the net compositions of the altered rock are plotted with reference to their corresponding FV values.

b) Elemental Fluxes During Granitization

Initial Variance Illustrated on a Flux Diagram:

The effect of the primary variance of the quartzites is clearly indicated on plots where samples of the three facies of rocks are distinguished. An example, using the element **sodium**, is given in Figure 1. The fields of **quartzite, transitional rocks** and **"granite"** are outlined to show the large extent of the overlap caused by the initial variability. However, it can also be observed that the **transitional** and **"granite"** fields are offset towards higher FV values and become progressively smaller. These trends are also portrayed in Table 2. It can be concluded from this illustration that individual sample data are generally unreliable as indicators of geochemical fluxes, but the trends of the facies means or of the entire collection of data represent the actual flux patterns. Flux trends can thus be interpreted from the facies means in Table 1.

Summary of Elemental Mobility Patterns:

Flux patterns can also be illustrated by suppressing the printing of the individual data points while representing its trend by a cubic regression curve. This has been done in the synoptic plots in Figure 2. Before commenting on the results, it should be noted that the ends of the regression curves are unreliable inasmuch as volume change factors of less than 0.456 and greater than 3.56 are lacking; the trends of the curves between these limits are controlled by the data.

The meaningful central portions of the trend lines for the "immobile elements" Ti, P, V, Y, Zr, La, Ce, Dy and Yb are all essentially flat, indicating, as required by the recognition of these elements as immobile, that little or no systematic change occurred in them. The central portions of the Zn, B and Th curves are all essentially flat as well. Boron appears to increase in the high-FV samples but the centre of the B curve is distorted by the presence of some minimum detection limit data. Zinc has an unusual upwardly concave shape but these data have a very high variance, especially at low FV-values, so little emphasis should be placed on this pattern. Thorium is also a high-variance element which shows no systematic flux pattern over most of the alteration range.

The elements Al, K, Na and, to a much lesser degree, Ca all increase towards higher FV-values. The ratio (K + Na + 0.5Ca)/Al, with the elements expressed in molecular proportions, changes from 0.66 (c = 0.42) in the primary **quartzites**, through 0.68 (c = 0.26) in the **transitional** rocks to 0.89 (c = 0.06) in the **"granites"**. As the ratio for muscovite is 0.33 and that for feldspar 1.00, this sequence expresses the change from a micaceous quartzite to a feldspathic granite, the decreasing coefficient of variation marking the increasing mineralogical uniformity of the rocks.

The elements Ba, Rb, Sr and Cu show notable increases in the course of granitization, but Au and S lead in this respect, each increasing by about two orders of magnitude.

The only element indicated as being progressively lost during granitization is Nd.

Oxidation Ratio Changes:

The initial quartzites have a relatively high oxidation ratio ($Fe^{3+}/(Fe^{3+} + Fe^{2+})$), suggesting that some oxidation affected them during their depositional period and that this parameter was probably not modified during their metamorphism. The values for the **transitional** and **"granite"** facies, however, decrease substantially, indicating that the granitization process was accomplished by relatively reduced fluids. These relationships are illustrated in Figure 3.

5. Genetic Interpretation

Field and petrographic observations indicate that the Frontier granite was formed after one episode of regional deformation and before a second one. It was also subsequently fractured and invaded by possibly two ages of mineralized quartz veins. The granite, therefore, has a multi-episodic history, the implications of which must be taken into account during this interpretation.

The identification of the Frontier granite as a metasomatic product of *granitization* of a quartzite protolith depends upon the initial identification of the immobile elements being correct. This identification was based on repeated clustering patterns of these elements on histograms of *zero change volume factors* calculated using

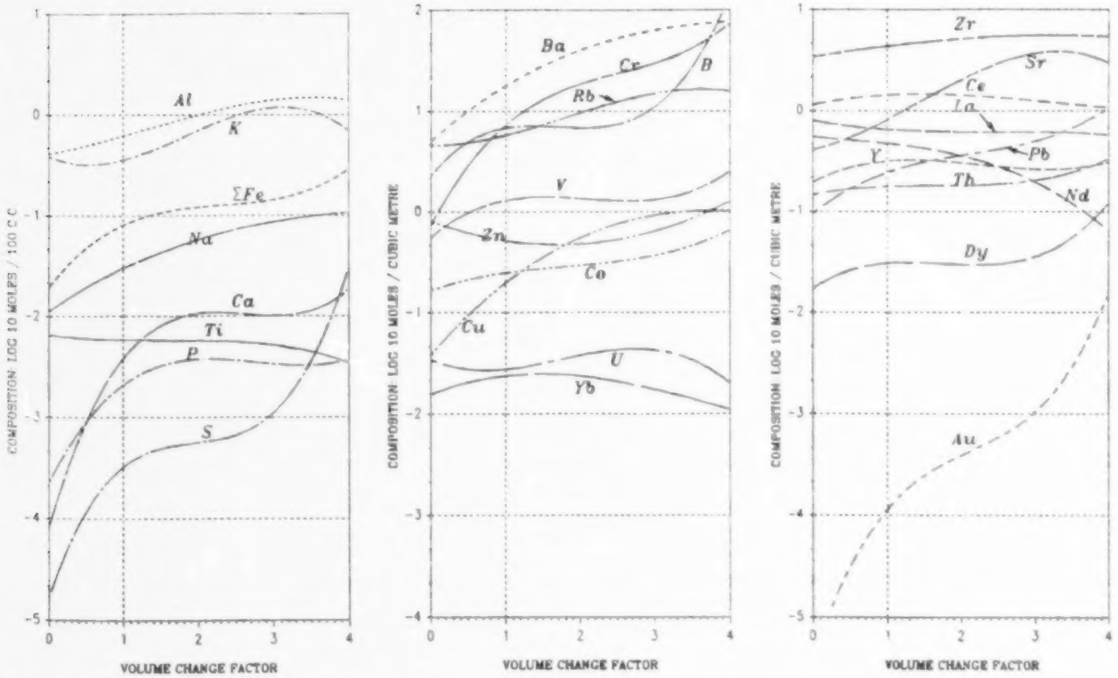

Figure 2 - Synoptic plots of element fluxes for derivation of the Frontier granite from quartzite protoliths. Curves are computer-generated cubic regression curves; the data points have been suppressed for clarity. Concentrations are expressed as in Figure 1.

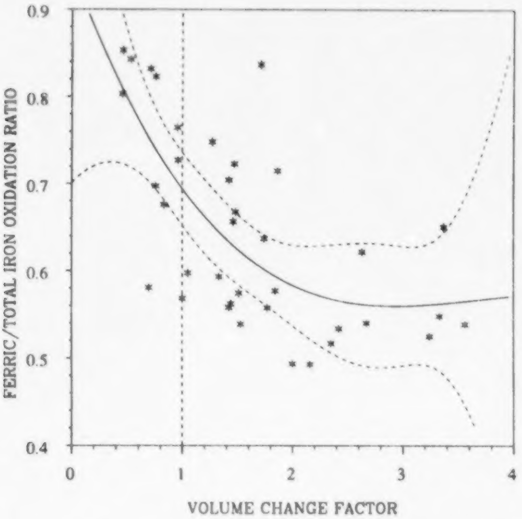

Figure 3 – Oxidation ratios (Fe/(Fe + Fe)) for rocks of the Frontier granite suite plotted against volume change ratios. The central (solid) curve is the cubic regression line and the flanking (dashed) curves are 95 percent confidence lines.

Gresens' equation. Those elements that were identified as immobile consist primarily of the rare earth elements La, Ce, Dy and Yb, and the high field strength elements P, Y and Zr. Thorium, which is also a high field strength element, probably also behaved as an immobile element (Figure 2) but was not recognizable as such due to its relatively high primary variance. Titanium and vanadium are both transition series metals. All these elements frequently fall into the immobile element category because: 1) they are neither easily complexed nor transported except in halogen-enriched fluids; 2) they are firmly locked into refactory mineral phases; or 3) if present in minerals that are unstable during alteration, they are efficiently incorporated into relatively abundant stable phases formed during alteration.

The elements introduced in largest amounts are Al, the alkalis (especially K) and probably Si. Notable trace element introductions include the large ion lithophile elements Rb, Sr and Ba. The protolith was gradually transformed from a *micaceous* aluminosilicate-rich assemblage to a *feldspathic* aluminosilicate-rich assemblage. The fluids may thus have been in equilibrium with a feldspathic source fluid. The further requirements of the model that the net volume and mass of the rock were approximately doubled during the emplacement process leads to the interpretation that the fluid was either relatively concentrated or involved extremely high rock/water ratios. The geological setting and the apparent lack of manifest large-scale hydrothermal alteration features leads me to prefer the first alternative. I suggest that the metasomatic fluid was hydrous magma derived by fractionation of a deeper granite pluton as opposed to a relatively dilute hydrothermal fluid. The main lithophile element additions appear to permit such a granitizing agent. The lowering of the oxidation ratios, suggestive of a reduced source fluid, is also compatible with this model.

The elements Au, S and Cu increase (Figure 2) at much higher slopes than most others. Asenic probably should also be included in this group as indicated by its facies means (Table 1), and Cr behaves similarly. The first three of these elements have been implicated with the quartz vein networks that cut the granites preferentially. Fluid inclusion studies reported by Quirt and Rees (1987) indicate that several types of vein-forming fluids and emplacement conditions are possibly represented. Some of the vein mineral assemblages indicate oxidizing conditions contrasting with the earlier granitization. The source of the vein fluids is not apparent from this limited study inasmuch as the available samples were selected to be representative of the **"granite"**, not the veins, although samples totally free of vein material were not generally obtainable.

The similar flux patterns for Au, Cu and S (and probably As) suggest they were introduced into the granite in association and occur in the ubiquitous pyrite, although it should be noted that the Au distribution is very erratic and in individual samples there is a poor correlation between high S and high Au. The material in the veins may represent later remobilization of Si and the metallic constituents into dilatent fractures, although the addition of Cr may mean an additional external source was involved. This question needs further study before an unequivocal answer is possible.

6. Caveat

The interpretation advanced in this study is based on an assessment of the lithogeochemical data. The author has not had the opportunity to examine these rocks in the field; therefore, the proposal is presented cautiously and is open to revision with further input of relevant observations and/or data.

7. Conclusions

The granitization model appears from this study to be permissible but, as formulated herein, it requires an approximate doubling of the initial rock mass and volume and a granitization fluid that most likely has the properties of a low-viscosity hydrous magma, probably the end fraction of a differentiating granite pluton at depth. It is tentatively suggested that Au, Cu, S and As were introduced at the time of granitization but have been partly segregated into late quartz veins several times since the formation of the Frontier granite.

The conclusions of this study are quite different than those proposed by Quirt and Rees (1987) and Quirt (1987) based on the same data. Quirt (1987) stated that volume increases do not correspond to field evidence, although the nature of this evidence was not documented, so he chose a representative volume change factor of 0.9 for the **quartzite** and **transitional rocks** to **"granite"** transformation. This value permitted minor additions of Si to form the veins included within the samples. The consequences of this assumption are that all the elements indicated as immobile in this study must be preferentially leached during granitization along with substantial amounts of Al, K, Fe, Na, Ca and most of the trace elements; in fact, almost everything except Si, Au, S and As. This model has the problem of providing a mechanism for achieving such extensive and selective leaching and in explaining the eventual repository of the leached material. Careful field structural studies are required to establish whether the two-fold volume increase proposed in this study or the 10 percent volume loss preferred by Quirt (1987) is more justified.

8. References

Babcock, R.S. (1973): Computational models of metasomatic processes; Lithos, v6, p279-290.

Barker, D.S. (1983): Igneous Rocks; Prentice-Hall Inc., Englewood Cliffs, N.M., 417p.

Binns, R.A. and Appleyard, E.C. (1986): Wallrock alteration at the Western System of the CSA mine, Cobar, New South Wales, Australia; Applied Geochem., v1, p211-225.

Gresens, R.L. (1967): Composition-volume relationships of metasomatism; Chem. Geol., v2, p47-65.

Quirt, D.H. (1987): Frontier prospect – lithogeochemistry and mass balance calculations; unpubl., internal rep., Sask. Res. Counc., 8p.

Quirt, D. and Rees, M. (1987): Current research in mineral deposits at the Saskatchewan Research Council; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p160-163.

Sibbald, T.I.I. (1984): Gold metallogenic studies, Goldfields area; *in* Summary of Investigations 1984, Sask. Geol. Surv., Misc. Rep. 84-4, p116-121.

Sibbald, T.I.I. and Jiricka, D.E. (1986): Geology of the gold deposits, Goldfields, Saskatchewan; *in* Clark, L.A. (ed.), Gold in the Western Shield; Can. Inst. Min. Metall., Spec. Vol. 38, p412-414.

Taylor, G.F. and Appleyard, E.C. (1983): Weathering of the zinc-lead lode, Dugald River, north-west Queensland: I. the gossan profile; J. Geochem. Explor., v18, p87-110.

Biogeochemical Studies of Precious Metals in Saskatchewan, 1988

Colin E. Dunn[1]

Dunn, C.E. (1988): Biogeochemical studies of precious metals in Saskatchewan, 1988; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4

This report constitutes an update on continuing field and laboratory investigations by the Geological Survey of Canada (GSC) related to biogeochemical exploration for gold in the La Ronge Domain and MacLean Lake Belt, and studies of platiniferous material from the Rottenstone Domain.

1. Developments in the Analysis of Vegetation for Platinum Group Metals (PGM)

It has been known for several years that plants are able to accumulate PGM to detectable levels (a few ppb in ash). However, a practical drawback to their use in biogeochemical exploration has been the requirement to collect large volumes of material in order to obtain sufficient ash (10 g) to permit quantitative determinations.

A cost-efficient method has been developed recently at the GSC whereby gold, platinum and palladium can be determined in 1 to 2 g samples of ash to detection limits of 0.5 to 2 ppb. The potential advantage of the new method over a fire-assay/ICP-MS (inductively coupled plasma mass spectrometry) determination is that there is no possibility of contamination from impure fire-assay "blanks". Therefore, theoretically, more precise data can be obtained on smaller samples. The method involves ashing at 870°C, acid decomposition, tellurium coprecipitation of the elements, and analysis by graphite furnace atomic absorption spectrometry (GFAAS) or ICP-MS (Hall et al., in press). Determinations on material ashed at different temperatures indicate that platinum, palladium and gold contained in tissues of spruce, alder, pine and birch show little, if any, tendency to volatilize during ashing up to 870°C.

a) Rottenstone Domain Field Studies, NTS 74A-7 (Lat. 56°20', Long. 104°50')

On the east shore of Rottenstone Lake (Figure 1), a small body of pyroxene-rich rock known as the "Hall" deposit was mined out in the sixties for rich accumulations of nickel, copper and precious metals. The body was interpreted as a roof-pendant with an average thickness of 8 m and a length of a few tens of metres, surrounded by gneissose metasediments. A cover of up to a few metres of sandy till is capped by an immature podzol. For 20 years the mine site has remained undisturbed, permitting natural regrowth of vegetation. This is proving to be an ideal field laboratory for examining the relative concentrations of a wide range of elements in common species of the boreal forests. It is suitable for comparing the merits of biogeochemistry with those of till and soil geochemistry in defining down-ice dispersion of precious metals where there is thin till cover.

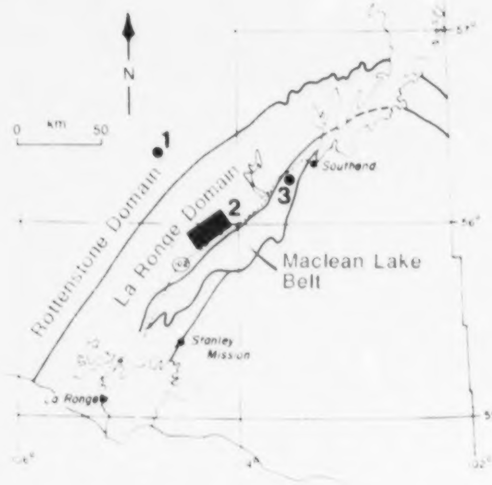

Figure 1 – Location of study areas: 1, Rottenstone Lake; 2, Star Lake; 3, Kotiniak Lake.

A brief period was spent in the summer of 1987 simultaneously collecting soils and bulk tills (W.B. Coker, GSC; J.E. Campbell, Saskatchewan Research Council), and black spruce twigs (C.E. Dunn). Sampling was confined to 1 km down-ice and a few sites up-ice from the abandoned pit (Figure 2).

Moderate to strong enrichment of precious metals, base metals, and pathfinder elements (selenium, bismuth and arsenic) was found in spruce twigs for a distance of less than 200 m down-ice. Weak palladium (6 to 8 ppb) and gold (20 to 22 ppb) enrichment was present in ashed spruce twigs 1 km distant, where the few soils and tills analyzed yielded no detectable concentrations of these metals. The heavy mineral concentrates (HMC) did, however, indicate platinum enrichments. At three sites up-ice from the pit, precious metal enrichments reported earlier (Dunn, 1986a) were found in the twigs and HMC (sites 1, 2, 3, Figure 2 and Table 1). This suggests that

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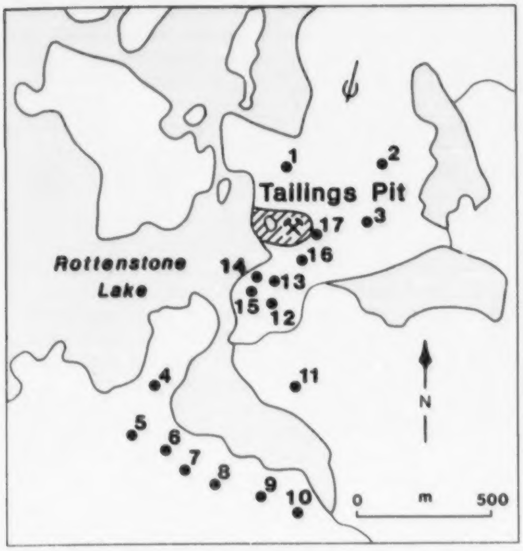

Figure 2 - Locations of B horizon soil, bulk till and back spruce twig samples, Rottenstone Lake. See Table 1 for analytical results.

there may be an area of bedrock enrichment of these metals to the north. Airborne contamination of the vegetation around the pit seems an unlikely source of the metal enrichment, since the HMC component of the tills is also rich in PGM.

Table 1 gives a comparison of precious metals in the different sample media. To date, seven soils and tills have been analyzed, whereas data are available for all the HMC and twigs. These data indicate that only the HMC and the spruce twigs are of value in detecting platinum. Locally, platinum is enriched in the HMC but not in the vegetation. Gold tends to behave in a similar manner to platinum. Palladium presents a different picture, being detectable in only two soil samples, absent in the tills and HMC, yet appreciably enriched in twig ash. The inference is that palladium remains in solution in groundwaters, and is absorbed by the plant roots.

It appears that, in light of the simplicity and cost-effectiveness of the biogeochemical method, a preliminary screening of an area may be undertaken by vegetation analysis. More detailed but more costly information can be obtained from the HMC recovered from bulk (7 to 10 kg) samples of till, preferably collected from areas highlighted by the biogeochemistry. The soils and tills were not informative in this area.

b) Inter-Species Accumulation of PGM at Rottenstone Lake

A comprehensive selection of plant species from near the Hall deposit was collected, dissected and analyzed for 45 elements. Table 2 summarizes data for several

Table 1 - Platinum, Palladium and Gold in B-Horizon Soils, Bulk Tills and Ashed Spruce Twigs, Rottenstone Area (See Figure 2 for Sample Locations)

	Platinum (ppb)				Palladium (ppb)				Gold (ppb)			
Site	Soil	Till		Spruce	Soil	Till		Spruce	Soil	Till		Spruce
No.	C,M,F	C,M,F	HMC	Twigs	C,M,F	C,M,F	HMC	Twigs	C,M,F	C,M,F	HMC	Twigs
1			26	25			nd	99			286	19
2	nd	nd	197	19	nd	nd	nd	25	nd	nd	88	15
3			2	26			nd	92			253	23
4			2	4			nd	8			39	16
5	nd	nd	1	<2	nd	nd	nd	6	nd	-,-,4	33	13
6	nd	nd	14	<2	nd	nd	nd	8	nd	-,-,3	113	8
7			515	<2			nd	6			18	7
8			20	<2			nd	<2			56	<1
9			274	<2			nd	3			54	5
10	nd	nd	878	<2	7,12,18	nd	nd	<2	2,2,17	nd	435	<1
11			47	<2			nd	<2			115	<1
12	nd	nd	139	<2	nd	nd	nd	<2	nd	nd	21	<1
13			107	294			nd	666			<1	125
14			32	41			nd	60			43	15
15			40	<2			nd	5			10	<1
16	nd	nd	4504	346	31,10,8	nd	5	517	2,-,1	nd	<1	95
17	nd	nd	353	468	nd	nd	nd	1318	-,67,-	-,-,63	58	265

C	"Coarse" (-10 to -80 mesh fraction)
M	"Medium" (-80 to -250 mesh fraction)
F	"Fine" (-250 mesh fraction)
HMC	Heavy mineral concentrate from tills
nd	Below detection levels for all size fractions
-	indicates below detection levels, which for the soil and till fractions are 15 ppb Pt, 2 ppb Pd and 1 ppb Au; soil and till data from W.B. Coker (pers. comm.)

Table 2 – Metal Concentrations in Ashed Plant Tissues, Hall Deposit, Rottenstone Lake

	(ppb)					(ppm)								(%)
Sample Medium	*Pt*	*Pd*	*Rh*	*Ir*	*Au*	*Ni*	*Co*	*Cr*	*Zn*	*As*	*Se*	*Te*	*Bi*	*Ash*
Black spruce twigs	800	1443	72	62	276	690	36	550	870	5	11	1.7	4.1	2.2
Black spruce bark (outer)	1187	1662	57	54	336	750	42	1400	460	5	9	2.0	4.8	3.8
Black spruce bark (inner)	126	212	6	<3	40	240	14	160	1900	1	–	–	–	3.4
Black spruce needles	83	244	6	<4	49	200	7	77	520	2	3.6	<0.3	0.5	4.0
Black spruce trunkwood	89	70	<2	<3	17	220	10	58	1800	1	3	<0.3	0.4	0.37
Birch twigs	125	306	11	<5	57	1300	110	63	8900	1.9	5.1	0.8	0.7	1.0
Birch leaves	87	326	10	<4	54	590	32	84	2500	1.6	6.5	0.4	0.7	4.0
Birch trunkwood	10	45	<2	<5	14	420	70	45	9200	1.1	1.3	<0.3	0.2	0.47
Alder twigs	62	170	13	<5	43	800	160	50	2200	1.6	1.2	<0.3	0.4	1.1
Alder leaves	35	158	3	<5	31	930	150	48	810	2.1	1.7	<0.3	0.3	4.4
Willow twigs	16	74	<2	<4	15	490	69	300	3800	1.1	1.4	<0.3	0.2	1.4
Willow leaves	–	–	–	<4	12	500	72	19	810	0.8	1.1	<0.5	0.3	5.9
Labrador tea twigs	166	368	14	15	70	1300	46	170	460	2.8	9	0.9	1.6	2.0
Labrador tea leaves	279	499	28	15	104	850	23	190	350	3.1	5.2	0.8	1.8	3.9
Marsh grass	18	30	<2	<7	5	2400	60	35	360	0.8	2.3	<0.3	0.2	6.5
Background[1]	<5	<2	<2	<2	5–20	<50	5	5–10	500–10,000[2]	<1	<1	<0.3	<0.1	[2]

[1] General concentrations encountered in common species of the boreal forest

[2] Strongly species- and plant organ-dependent

Pt, Pd, Rh and Au data by fire-assay/ICP-MS (Acme Laboratories, Vancouver); As, Se, Te and Bi data by hydride generation/ICP (Acme Laboratories, Vancouver); other elements by instrumental neutron activation analysis (Activation Laboratories, Brantford, Ontario)

Latin binomials of the species listed are: black spruce, *Picea mariana*; birch, *Betula papyrifera*; alder, *Alnus crispa*; willow, *Salix discolor*; labrador tea, *Ledum groenlandicum*; grass species not identified

elements which exhibit wide ranges of concentration among species and tissue types. Material analyzed was ashed at 470°C – the higher temperature ashing for PGM mentioned earlier is not a prerequisite for the fire-assay analysis from which these precious metal data are derived. For comparison, general background levels of elements in common species of the boreal forests are given at the bottom of the table. It is apparent that precious metals, base metals, chromium and the "pathfinder" elements arsenic, selenium, tellurium and bismuth are preferentially concentrated in spruce in the twigs and outer bark scales. Needles, inner bark and trunkwood have lower concentrations of all the listed elements except zinc.

In the deciduous trees, the partitioning of most elements between twigs and leaves is far less pronounced than in the conifer. Noteworthy differences in partitioning are chromium in willow, zinc in birch, willow and alder, and nickel in birch. There is strong enrichment of zinc in the woody parts of birch, and enrichment of nickel in marsh grass.

These data provide valuable baseline information on the propensity of different plant organs to accumulate metals, and serve to guide the explorationist in the selection of the biogeochemical sample media most sensitive to changes in metal concentrations in the substrate.

2. Gold in the La Ronge Domain

a) Data Integration

Following the acquisition by the GSC, late in 1987, of a spatial data analysis system, work has been underway by H. George and G.F. Bonham-Carter to integrate data from a biogeochemical survey of an area around Star Lake (Figure 1) with other geoscience data sets from the same area (geology, structure, geophysics, airborne and satellite imagery). The model for gold mineralization that was examined took into account 1) gold in spruce bark and alder twigs above the 90th percentile, 2) the proximity to structural lineaments and 3) the proximity to intrusive rocks. Several areas were identified which met these basic constraints, and were the foci of field follow-up investigations in 1988. Currently, mathematical models are being tested to refine coincident anomalies in various data sets. A report on this study is being compiled (H. George, pers. comm.).

b) In-Fill Sampling and Follow-Up Investigations

A survey in the vicinity of Star Lake was conducted in 1986, which involved the multi-element analysis of ashed spruce bark and alder twigs obtained from about 600 sites within a 150 km^2 area (Figure 1). Preliminary reports (Dunn, 1986b, 1987) outlined several areas yielding anomalous concentrations of gold, and locally molybdenum, antimony and cesium. In July 1988, a follow-up program of site investigation and detailed sampling was undertaken at several of these localities. In addition, sampling was conducted in areas not previously sampled, including the recently discovered Jasper Zone of gold mineralization near Fork Lakes. The following observations are made on analytical data received to date:

Jasper Pond, NTS 73P-16 (Lat. 55°57', Long. 104°17'):

Three sample media (spruce bark scales, alder twigs and labrador tea twigs) were collected at 100 sites in this area, at 50 m intervals along several cut lines. The survey area is underlain by intermediate rocks of the Fork Lakes Pluton. Close to the discovery zone, gold concentrations were found to be 207 ppb in spruce bark and 41 ppb in alder. Across an adjacent bog, labrador tea twigs yielded 38 to 289 ppb Au in ash, corroborating the patterns of gold enrichment found in this plant by the Saskatchewan Mining Development Corporation (V. Sopuck, pers. comm.). Other locations with gold enrichment in the vegetation are scattered across the study area. Several alder samples yielded anomalous gold concentrations (40 ppb) near the northwest end of Broeder Lake, located 400 m northeast of Jasper Pond. Shear zones have been identified in this area.

"Nameless" Lake, NTS 73P-16 (Lat. 55°59', Long. 104°16'):

This previously unsampled area, was selected for study because of a predicted zone of interest derived from the data integration analysis, and because of the presence of a shear zone of similar character to other zones in the area which are gold bearing. Bedrock ranges in composition from granite to monzonite, with some amphibolitic metavolcanics. Gold concentrations range from 10 to 82 ppb in 24 samples, suggesting gold enrichment in the bedrock, close to the projected occurrence of a shear zone. Slight arsenic enrichment (up to 12 ppm) is coincident with elevated gold levels.

Pesimokan Lake, NTS 73P-16 (Lat. 55°58', Long. 104°13'):

Numerous vegetation samples obtained on several visits to this area have yielded anomalous concentrations of gold. The survey area transects sheared metavolcanics of the McLennan Lake Tectonic Zone (MLTZ) and felsic rocks of the Island Lake Pluton. Rock samples collected by a GSC geophysics crew in 1987, who were following up a pronounced linear magnetic anomaly spatially related to the MLTZ, contain several percent magnetite. The magnetite is intergrown with the sulphides pyrite, pyrrhotite, chalcopyrite and molybdenite. Gold concentrations up to 3000 ppb are present (B.W. Charbonneau, pers. comm.). Vegetation samples from about 80 sites are being processed in an attempt to assist in locating additional sources of gold enrichment, and to understand the processes which have given rise to the biogeochemical anomaly.

Liggett Bay, NTS 73P-16 (Lat. 55°55', Long. 104°18'):

On the south side of McLennan Lake, a peninsula juts out to enclose Liggett Bay. Spruce bark samples obtained in 1986 yielded up to 56 ppb Au. An investigation of this site indicates that the source of the anomaly is a coarse-grained pegmatite dyke that cuts across the peninsula. No visible mineralization was observed, but rock samples are being analyzed.

3. Gold in the MacLean Lake Belt

a) Koliniak Lake, NTS 64D-1 (Lat.56°12', Long. 103°34'):

It was noted earlier (Dunn, 1987) that phenomenal concentrations of gold (over 200,000 ppb) and silver (380 ppm) were found at this locality in the combined ash of alder twigs and leaves, from plants growing over basic metavolcanics. Scanning electron microscopy of these ashes has dislosed 2 to 3 micron and sub-micron sized grains of gold, which show no obvious crystalline structure. It appears that some of the larger grains may be coagulated particles of about 0.1 micron. At this time, the source of the gold is unknown. It is not clear whether the gold is airborne contamination, field or laboratory contamination (although assurances were given from parties involved that every care was taken), or actual accumulation in the plant material by translocation from roots to the leaf tips. Resampling of two localities this summer failed to repeat these high precious metal enrichments, although weak gold anomalies in the vegetation were found.

4. Acknowledgements

I thank the many organizations and individuals who have provided me with help and information related to this project. In particular, I thank my field assistants Steve Adcock and Louise Fortin, and Roxane Banville who acted as party leader for part of this year's field season.

5. References

Dunn, C.E. (1986a): Biogeochemistry as an aid to exploration for gold, platinum and palladium in the northern forests of Saskatchewan, Canada. J. Geochem. Explor. V25, p21-40.

________ (1986b): Biogeochemical studies in the Saskatchewan Gold Belt, 1986; *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep. 86-4, p129-135.

________ (1987): Precious metals in vegetation from northern Saskatchewan, 1987; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p136-139.

Hall, G.E.M., Pelchat, J.C. and Dunn, C.E. (in press): The determination of Au, Pd and Pt in ashed vegetation by ICP – mass spectrometry and graphite furnace atomic absorption spectrometry; J. Geochem. Explor.

Quaternary Geology and Till Geochemistry of the East Amisk Lake Area: Progress Report

Janet E. Campbell[1]

Campbell, J.E. (1988): Quaternary geology and till geochemistry of the East Amisk Lake area: progress report; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

The Saskatchewan Research Council (SRC) has documented the Quaternary geology in the East Amisk Lake area, including type, distribution and stratigraphy of deposits, source of materials, and direction and distance of transport. This information is used to determine the most useful sampling media and most effective techniques for drift prospecting.

The 210 km^2 study area covers the region from Creighton south to the limit of the Precambrian Shield and from the Manitoba border west to Amisk Lake (Figure 1). The area was chosen because of the presence of known gold deposits and showings, and for the complexity of the Quaternary geology, which includes the influence of glacial Lake Agassiz. A preliminary report has been released describing the Quaternary geology, as well as the till geochemistry and heavy mineral analyses (Campbell, 1988). Analytical data and results are included in the appendices. Maps of the Quaternary geology accompany the report. A final report to be published by the SRC will be similar in scope to previous reports concerning the Waddy Lake (Campbell, 1986) and Sulphide - Hebden Lakes (Campbell, 1987a) areas.

1. Procedure

Airphoto interpretation of the surficial geology was completed prior to field mapping at the scale of 1:20,000. Ground-checking was carried out at 218 sites. Hand-augered holes or small pits were dug to an average depth of 0.8 m at most of these sites.

Subsurface stratigraphic information was obtained by drilling eleven roto-sonic holes along Highway 167 and the West Arm Mine road to depths ranging from 2 to 11.6 m. It is assumed that the holes terminated at bedrock, although this is not certain as the roto-sonic drill cannot discriminate bedrock from very large boulders. Basal till was encountered in six of the eleven holes.

Although representative samples of the various deposits were collected, the main emphasis of collecting was to sample the till, where possible particularly from the C-horizon. Seventy-five bulk till samples (6 to 10 kg) were collected, including nine from the drillholes. The up-ice side of ridges and outcrops was the preferred surface sampling site.

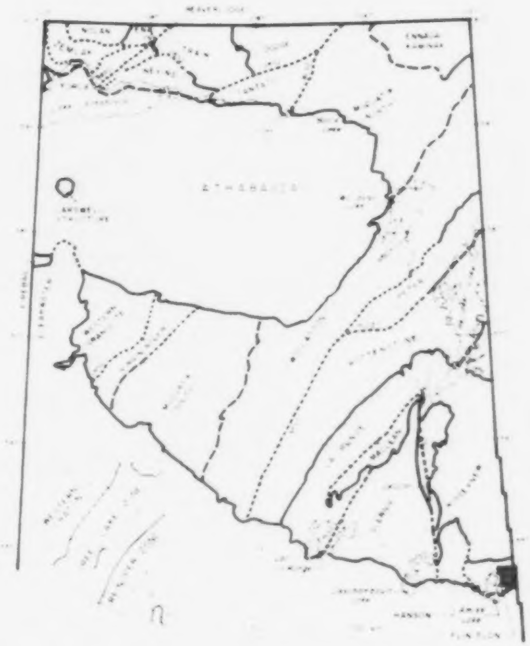

Figure 1 - Location of the study area.

2. General Geology

Drift cover in the East Amisk Lake area is thin and discontinuous in comparison to the La Ronge Belt (Campbell, 1986, 1987a), except in the south where bed rock relief is lower. The approximate proportions of surficial materials occurring in the area are: 40 percent bedrock, 25 to 30 percent glacial till, 15 to 20 percent glaciolacustrine, 10 to 15 percent organic and up to 5 percent glaciofluvial. Based on the roto-sonic drillholes and mineral exploration wacker drilling programs, drift thickness is highly variable. Although 11.6 m was the deepest hole drilled during this study, depths greater than 21.5 m have been recorded in topographic lows tested by wacker drilling (M. Koziol, pers. comm., 1987).

Based on information obtained from exposures and roto-sonic drillholes, the stratigraphic sequence is:

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[1] Environment and Resources Branch, Saskatchewan Research Council, Saskatoon

6) Organic material
5) Grey/brown silty-sand till
4) Lacustrine sediments (sand, silts, clays)
3) Fluvial sediments (sands, gravels)
2) Grey/brown sandy till
1) Bedrock

All units may not be present at any one site. A brief description of the surficial units has already been published by Campbell (1987b, 1988).

3. Sample Analysis

Till sample analyses included geochemical analyses, heavy mineral separation and gold grain documentation. Fractionation tests were performed on selected samples containing gold, in order to identify any grain-size relationships. Textural analysis of selected samples has been useful in characterizing the deposits.

In all, 112 till samples (including bulk till samples) were analyzed at the SRC for Pb, Ni, Co, Cu, Zn, Ag, As, Au and W. The samples were wet-sieved to 0.1 mm (-150 mesh) and analyzed by the atomic absorption method (GFAA).

The SRC employs a shaking table and Mosley superpanner for heavy mineral separation of bulk till samples. The samples are panned manually to separate the gold grains, which are then described and counted before the concentrates are assayed. The results from the gold grain counts as well as the geochemical and heavy mineral analyses will be compared to determine the most representative analyses.

These till analyses provide background information enabling interpretation of mineral distribution, especially gold, and help in the identification of the till unit most effective for exploration sampling.

4. Till Geochemistry

Gold was found by geochemical and visual analyses in both the upper and lower till units. As the upper till occurs only sporadically, it is difficult to trace mineral dispersion in this unit. Geochemical results from the lower till reflect the known mineral occurrences (e.g., Au, Cu, Zn and W) and outline regionally anomalous areas such as Phantom Lake.

Regional threshold values for gold in the East Amisk Lake area are 17 ppb in the fine fraction (<0.1 mm) and 5 gold grains for the heavy mineral fraction. There is no geochemical correlation between the fine and heavy mineral fractions. Ninety-one percent of the bulk till samples yielded visible gold. Gold grain counts varied from 0 to 13 and the grains range from less than 50 μm to 800 μm in size. The gold is predominantly fine grained (94 percent <200 μm).

Gold is its own best pathfinder, due to the fact that there are no associated minerals evident in the till on a regional scale. This was expected, since several types of gold mineralization are present in the area. To date, no glacial dispersion trains for economic minerals have been delineated in the East Amisk Lake area.

5. Summary and Conclusions

Although interpretation of the analytical results is not complete, several significant preliminary observations can be made:

1) The drift cover in the East Amisk Lake area is thin in comparison to that in the La Ronge Domain. The rugged nature of the bedrock topography in the northern portion of the study area is associated with great variability in drift thickness over short distances.

2) Two distinct tills are present in the area. The upper grey/brown silty-sand till is thin and discontinuous. The lower, grey sandy till is more prevalent. Variations in the lithology of the lower till reflect the variations in the local bedrock source, making it the preferred sampling media.

3) Two ice frontal positions marked by ice contact/lacustrine deposits have been identified at 1) Mosher-Konuto-Amisk Lakes and 2) Douglas-Boot Lakes. The Quaternary geology is complex in these areas.

4) Glaciolacustrine sediments are found at elevations as high as approximately 338 m. The entire study area was inundated by glacial Lake Agassiz. Maximum lake level is estimated to have been between 400 and 427 m (Schreiner, 1984).

5) Four sets of crosscutting striae indicate an older ice direction of 190 to 208°, which is overridden by a younger readvance flowing in a more southwesterly irection at about 216°. The most common direction of ice flow is 204 to 208°.

6) Geochemical results indicate that bulk till sampling is more effective than soil sampling for regional geochemical surveys for gold in this region.

7) Preliminary inspection indicates that regional geochemical threshold values for gold in till are 17 ppb (<0.1 mm fraction) and 5 gold grains in bulk till samples.

8) Drift prospecting has limited application in the East Amisk Lake area. The most useful technique is overburden drilling in topographical lows which are commonly filled by muskeg.

6. References

Campbell, J.E. (1986): Quaternary geology of the Waddy Lake area, applied to prospecting for gold; Sask. Res. Counc., Rep. R-842-1-E-86, 74p (plus 2 maps).

________ (1987a): Quaternary geology and till geochemistry of the Sulphide-Hebden Lakes area; Sask. Res. Counc., Rep. R-842-4-E-87, 74p (plus 1 map).

________ (1987b): Quaternary geology of the East Amisk Lake area, applied to prospecting for gold; *in* Summary of Investigations 1987, Sask. Geol. Surv.; Misc. Rep. 87-4, p148-150.

________ (1988): Preliminary report – Quaternary geology and till geochemistry, East Amisk Lake area, Saskatchewan; Sask. Res. Counc., Rep. R-842-59-E-88, 31p (pl
2 maps).

Activities in Data Analysis and Image Analysis at the Saskatchewan Research Council

Michel Mellinger[1]

Mellinger, M. (1988): Activities in data analysis and image analysis at the Saskatchewan Research Council; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

This contribution gives a summary of projects completed in the past year. In the area of data analysis, work was carried out in support of projects for which results are reported by the respective leaders elsewhere, as referenced below. In the area of image analysis, activities involved both work in support of lineament mapping projects and the establishment of autonomous image analysis capabilities in the SRC Data Analysis Group.

1. Data Analysis Activities

Till prospecting data were interpreted using multivariate statistical techniques to help decipher complex geochemical and textural interrelationships. The two projects involved dealt with the Amisk Lake area (Campbell, this volume) and the Dawn Lake area (Millard, 1988).

Multivariate data analysis was also applied to the interpretation of the Athabasca Group geochemistry (Quirt and Mellinger, 1988), for both major and trace element patterns.

Two geochemical projects are in progress. Firstly, a reinterpretation of the NEA/IAEA lake sediment survey (Coker and Dunn, 1981) is being carried out by taking field information closely into account, the goal being the ability to discriminate between geochemical signatures resulting from environmental factors and those which may be indicative of hidden mineralization (Mellinger, in prep.).

Secondly, interpretation of rock geochemistry related to the Nicholson Bay mineralization (Peiris and Parslow, this volume) is being carried out in an attempt to decipher possible multistage mineralization processes.

Data analysis expertise gained during the past several years addressing geochemical and geological problems is now being applied, also with success, to nongeological areas including agriculture, soil science and environmental studies.

2. Image Analysis Activities

Following a successful pilot project on the Carswell Structure (see Mellinger, 1987) aimed at the integrative interpretation of exploration surveys, it was decided to acquire at SRC an image analysis system with processing capabilities adapted to this type of project. This system, expected to be operational in November 1988, provides all required image processing and mathematical morphology algorithms.

Another application of image analysis in which the author, with the SRC Remote Sensing Centre, has been active during the past year is that of lineament mapping by use of satellite imagery; several contracts for the mineral industry were successfully carried out. The new image analysis system will enhance capabilities of the present remote sensing system in such projects by allowing further manipulation of extracted lineaments (e.g., determination of directional connectivity and textural characteristics).

3. References

Coker, W.B. and Dunn, C.E. (1981): Lake water and sediment geochemistry, NEA-IAEA Athabasca Basin–Wollaston Lake Test Area (64L, 74I); Geol. Surv. Can., Open File 779, 90p (plus 2 maps).

Mellinger, M. (1987): Integrative interpretation of exploration surveys by use of image analysis techniques: progress report; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p151-153.

Mellinger, M. (in prep): Integrating field information into the interpretation of regional geochemical data: the NEA/IAEA Athabasca Test Area lake sediment survey revisited; Geol. Surv. Can., Colloquium, November 1988.

Millard, M.J. (1988): Quaternary geology and drift prospecting, Dawn Lake area, northern Saskatchewan; unpubl. M.Sc. thesis, Univ. Sask., 171p (plus 2 maps).

Quirt, D.H. and Mellinger, M. (1988): Regional sandstone lithogeochemistry and uranium exploration in the Athabasca Basin; Geol. Assoc. Can./Mineral. Assoc. Can., Joint Annu. Meet., St. John's, Prog. Abstr., v13, pA102.

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Reconnaissance Investigation of Pt, Pd and Au in Host Rocks of Saskatchewan Uranium Deposits

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Quirt, D. (1988): Reconnaissance investigation of Pt, Pd and Au in host rocks of Saskatchewan uranium deposits; *in* Summary of Investigations 1988; Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

During 1987/88, approximately 150 samples of host rocks from various uranium deposits in northern Saskatchewan were analyzed for platinum, palladium and gold. These were from several Athabasca Basin unconformity-type deposits and selected deposits in the Greater Beaverlodge area, and were taken close to or within uranium mineralization and from background unaltered material. The Pt, Pd and Au data and sample descriptions referred to in the following text are detailed in Quirt (1988). Most samples (118) were subjected to a fire assay concentration procedure followed by atomic absorption (Au) and inductively coupled plasma emission (Pt, Pd) analyses. Detection limits were 5, 5 and 1 ppb, respectively. The other samples (28) were analyzed for Pt and Pd by neutron activation, detection limits being 10 and 2 ppb, respectively.

1. Athabasca Basin and Diabase Dykes

a) Athabasca Group

The 43 Athabasca Group samples analyzed were mostly of normal, unaltered sandstones and siltstones, with representation from all formations and members (Ramaekers, 1979) except the uppermost Tuma Lake, Carswell and Douglas Formations, which are found only around the Carswell Structure. They were analyzed for Au, Pt and Pd to obtain background data for comparison with that from mineralized zones. Five samples were taken of kaolinitized Athabasca sandstones present above major shear zones in the basement rocks. In all of these the Pt and Pd contents are very low, at or near detection limit (Table 1). The average Au value is also very low (Table 2). No correlation is evident between the degree of alteration (kaolinitization, bleaching) of the sandstones and the precious metal content.

The Athabasca Group is cut by a number of northwesterly-trending diabase dykes. These dykes have a quartz-normative tholeiitic composition and have been dated at 1227 ± 11 Ma (Armstrong et al., in prep.). Without exception, analyses of typical pyritic diabase returned low values of Pt, Pd and Au (Tables 1 and 2).

b) Unconformity-Type Deposits

Also analyzed were Athabasca Group sandstones hosting the Midwest Lake, Collins Bay 'B', Dawn Lake, McClean Lake and Spring Point unconformity-type uranium deposits. Samples were taken from the lower Manitou Falls (MFa or MFb) Formation (Midwest Lake, Collins Bay 'B' zone, Dawn Lake and McClean Lake) and from the lower Fair Point Formation (Spring Point). Pt and Pd were typically low except in one sample showing 110 ppb Pd, and 53 ppb Au (Tables 1 and 2). The sample, included in Table 2, upwardly biases the average Pd value by 4 ppb. Similar results have been obtained by Hulbert (1987).

The samples contain variable amounts of Au, between 1 and 200 ppb. The average Au values for the Manitou Falls and Fair Point samples are similar, and substantially above that of background sandstone (Table 2).

It appears that no significant Pt or Pd concentrations are absent in the Athabasca Group, whether mineralized with uranium or not; however, gold appears to be enriched close to mineralization. Although the Spring Point occurrence is not highly mineralized in U, it does have a zone of strong host-rock alteration containing elevated Au values. This indicates that gold enrichment is related to the alteration process and not to the degree of uranium mineralization. Additional geochemical work should be carried out to determine the degree of enrichment and the distribution of Au in this environment.

2. Greater Beaverlodge Area

Four locations in the Beaverlodge and Goldfields areas were investigated for Au, Pt and Pd potential. The Nicholson Bay and Fish Hook Bay localities are not included in this survey due to their known U-Au-PGE mineralization. Of the four locations sampled here, three are specific mineral prospects or former mines, while the fourth, the Martin Group Basin, encompasses a much larger area. All sedimentary formations identified within the Martin Group (Langford, 1981; Mazimhaka and Hendry, 1984) were sampled.

a) Martin Group

A total of 20 samples of Martin Group clastics supplied by P. Mazimhaka (University of Saskatchewan) were analyzed for Pt, Pd and Au, as were five samples of Charlot Point Formation and Thluicho Lake Group sediments. All samples display low values of Pt and Pd, with all Pt and most Pd values at detection limit (Table 1). Au values, on the other hand, while also low, show some variability. No significant Pt, Pd or Au appear to be

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Table 1 – Ranges of Pt, Pd and Au values (ppb)

	Pt	*Pd*	*Au*
Athabasca Group	5 - 10	5 - 20	1 - 17
Athabasca diabase	5 - 30	10 - 50	9 - 18
Martin Group	5	5 - 60	1 - 48
Unconformity-type U deposits	5 - 10	5 - 110	1 - 200
Gunnar Mine	5 - 10	<2 - 10	1 - 49
Goldfields – unaltered quartzite	< 10	<2	3 - 33
– altered quartzite	< 10	<2	6 - 450
– "mine granites"	< 10 - 10	<2 - 7	35 - 900
– granitoid gneiss	< 10 - 10	<2	154 - 1761

Table 2 – Average[1] Pt, Pd and Au Values (ppb)

	n	*Pt*	*Pd*	*Au*
Athabasca Group	43	6	8	5
Athabasca diabase	16	8	23	12
Martin Group	25	5	7	9
Unconformity-type U deposits	30	7	12[2]	36
Gunnar Mine	6	7	6	15
Goldfields – unaltered quartzite	5	1	1	10
– altered quartzite	4	1	1	159
– "mine granites"	14	6	1	312
– granitoid gneiss	4	6	1	778

[1] detection limit values cut to 1/2 detection limit

[2] average biased by anomalous individual sample

present in these sediments, although the somewhat higher Au values may warrant further investigation.

b) Gunnar Mine

Rock types sampled include altered and unaltered host paragneisses, and the Gunnar "mine granite". The Pt and Pd values are uniformly very low, while the Au content is low but variable (Table 1). The highest Au values are from altered paragneiss (15 ppb), while the Gunnar granite sample contains a very low amount of Au (2 ppb).

c) Box and Athona Mines

As noted by Hulbert (1987), no significant Pt and Pd concentrations appear to be present in the Box or Athona "mine granites" (Tables 1 and 2), in adjacent granitoid gneisses (Athona mine), or in the neighbouring Tazin quartzites (Box mine). Pt and Pd values are at or below detection limit. Conversely, anomalous Au values are common in the "mine granites" as well as in the granitoid gneisses at Athona. The quartzites at Box, however, display low background Au values of 6 ppb or less (see section on Frontier below).

One sample from the central zone of a hematitic, albitized and carbonatized fracture ("sponge rock") in granitoid gneiss at the Athona mine was also analyzed. Again, Pt and Pd values are at detection limit, but the Au value is highly anomalous (Table 1). This result has significance for Au exploration in the Greater Beaverlodge area, as similar albitized fractures and associated zones of red (hematitic) albitite are commonly associated with the uranium deposits of simple mineralogy (see also Hulbert, 1987, p. 129). Further work is recommended to examine their precious metal potential.

d) Frontier Prospect

A number of samples were taken of Tazin quartzite, Frontier "mine granite" (a metasomatized equivalent of the quartzite) and quartzite adjacent to the "mine granite". No significant Pt and Pd concentrations appear to be present at the Frontier prospect, with all samples at detection limit for Pt and excepting one sample (Table 1), also for Pd. The Frontier "mine granite" gives anomalous Au values. Au values from the quartzite samples are varied; the quartzites near the "mine granites" range from background to anomalous and the relatively distal Tazin quartzites show background Au contents.

3. Conclusions

No significant Pt or Pd enrichment is observed in either the Athabasca or Martin Groups, or associated with unconformity-type uranium mineralization or Goldfields-type gold mineralization. Therefore, PGE mineralization present at the Nicholson and Fish Hook Bay prospects appears to be unrelated to either gold mineralization in the nearby Goldfields area or to the unconformity-type uranium mineralization typical of the Athabasca Basin, with which the Nicholson uranium mineralization has been correlated.

Gold is present in anomalous amounts in the granitoid gneisses at the Athona mine site, in the altered, transitional quartzites at the Frontier prospect and, as expected, in the associated "mine granites". The presence of elevated Au values in an albitized fracture in the Athona granitoid gneiss indicates the possibility of Au deposition in albitized rocks elsewhere in the Beaverlodge area. Further work is required to determine whether this Au enrichment is a result of local remobilization of pre-existing elevated Au values, such as is present in the granitoid gneisses and "mine granites", or is due to the direct introduction of Au along the fracture.

The Au enrichment associated with the unconformity-type mineralization (Tables 1 and 2; Quirt, 1988), although of lesser degree than in the Nicholson and Fish Hook Bay prospects, should be examined further to determine its scale and distribution. The occurence of Au in the Cluff Lake 'D' zone orebody (Tapaninen, 1975, and others) in recoverable quantities (Sibbald and Quirt, 1987) demonstrates the importance of further investigations.

4. References

Armstrong, R.L., Quirt, D.H. and Hoeve, J. (in prep.): Rb-Sr dating of diabase dykes in the Athabasca Basin, northern Saskatchewan; Sask. Res. Counc., Publ. R-855-3-A-88.

Hulbert, L. (1987): Investigation of mafic and ultramafic rocks, and platinum group element mineralization in northern Saskatchewan: preliminary findings; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p125-130.

Langford, F.F. (1981): The Martin Group in the greater Beaverlodge area; *in* Summary of Investigations 1981, Sask. Geol. Surv., Misc. Rep. 81-4, p38-43.

Mazimhaka, P.K. and Hendry, H.E. (1984): The Martin Group, Beaverlodge area; *in* Summary of Investigations 1984, Sask. Geol. Surv., Misc. Rep. 84-4, p53-62.

Quirt, D.H. (1988): Pt, Pd and Au data from samples of host rocks of Saskatchewan uranium deposits; Sask. Res. Counc., Publ. R-855-6-E-88, 6p.

Ramaekers, P. (1979): Stratigraphy of the Athabasca Basin; *in* Summary of Investigations 1979, Sask. Geol. Surv., Misc. Rep. 79-10, p154-160.

Sibbald, T.I.I. and Quirt, D.H. (1987): Uranium deposits of the Athabasca Basin; Geol. Assoc. Can./Mineral. Assoc. Can., Joint Annu. Meet., Saskatoon, Field Trip Guidebook No. 9., 73p.

Tapaninen, K. (1975): Geology and metallogenesis of Carswell area uranium deposits; Can. Inst. Min. Metall., Annu. Western Meet., Edmonton, Oct. 26-29, 1975.

Current Mineral Deposit Research at the Saskatchewan Research Council

David Quirt[1]

Quirt, D. (1988): Current mineral deposit research at the Saskatchewan Research Council; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

Work by the Saskatchewan Research Council's Mineral Deposits Group this year has concentrated on the Athabasca and Wollaston Groups (uranium), the Beaverlodge area (gold, uranium, platinum) and the Waddy Lake area (gold). Two studies of the Athabasca Group have been completed: sandstone lithogeochemistry (Quirt and Mellinger, 1988a, b) and diabase dyke Rb-Sr age-dating (Armstrong et al., in prep.) and geochemistry (Quirt and Mellinger, in progress). Also completed is a reconnaissance survey of Au, Pt and Pd in the host rocks of Saskatchewan deposits. The results of this survey are presented by Quirt (this volume). Preliminary results of field mapping carried out south of the Athabasca Basin in the Wollaston Domain are presented by Annesley and Madore (this volume).

1. Athabasca Basin

In cooperation with SRC's Data Analysis Group, a study of the regional sandstone lithogeochemistry of the Athabasca Group was carried out (Quirt and Mellinger, 1988a, b). Lithogeochemical data from core from regional drillholes remote from known uranium occurrences, as well as from core from drill holes in proximity to mineralization in the southeast corner of the Athabasca Basin were obtained. All clastic formations of the Athabasca Group were represented in the sample population.

The samples were analyzed for 12 major oxides and a minimum of 15 trace elements. The variation patterns in both major oxide and trace element data were studied using correspondence analysis to determine differences in mineralogy and the signatures of imposed geological processes.

The study shows, as expected, that the major element patterns reflect the sandstone petrography in a manner analagous to whole rock x-ray diffraction analyses. The trace element patterns are determined largely by accessory minerals containing B, Sr and Zr. Both sets of patterns appear to be relatively insensitive to stratigraphic variations and only two of the eight clastic formations are readily distinguishable geochemically: the Upper Wolverine Point Formation and the combined Upper and Lower Fair Point Formations. The use of lithogeochemistry as a regional mapping tool in the Athabasca Basin does therefore not appear to be very productive.

The major element patterns for sandstones proximal to the unconformity-type uranium deposits are similar to those for the sandstones remote from known mineralization (Mellinger et al., 1987). The trace element patterns are complex, however, indicating that:

1) lithogeochemistry is a suitable tool for the delineation of anomalous zones in the Athabasca sandstones, and
2) the accessory mineralogy data obtained by x-ray diffraction is complementary.

a) Diabase Dykes

A Rb-Sr age-dating study of diabase dykes intruding the Athabasca Group sediments has been conducted in collaboration with R. Armstrong of the University of British Columbia (Armstrong et al., in prep.). Previous isotopic dating studies have provided dates spanning nearly 500 Ma and 200 Ma by K-Ar and Rb-Sr methods, respectively. The Rb-Sr mineral isochron technique was used where individual mineral components could be separated and analyzed.

Eleven samples of diabase from six dykes were analyzed. Five dykes are in the Cree Lake area and the other is near the Midwest Lake uranium deposit. All of the new isochron dates are similar, regardless of dyke trend or location. The Cree Lake dykes yield isochron ages ranging from 1202 Ma to 1275 Ma, whereas the Midwest Lake dyke is dated at 1098 ± 97 Ma; however, it is much finer grained than the Cree Lake dykes, a factor which hampered the preparation of clean mineral fractions. The mineral fractions of the Midwest sample also show the lowest spread of Rb-Sr ratios found in the study and the isochron date error is so large that the oldest possible age is not statistically different from those of the Cree Lake dykes. The weighted mean of all results is 1227 ± 11 Ma, indicating that these dykes belong to the Mackenzie dyke swarm. The coincidence with dates obtained for unconformity-type uranium mineralization leads to the conclusion that dyke emplacement and uranium mineralization are related processes.

2. Other Studies

Current projects underway include gold-uranium-PGE studies in the Beaverlodge area, Athabasca Basin-re-

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(1) Energy and Minerals Branch, Saskatchewan Research Council, Saskatoon

lated investigations, and a lithogeochemical gold project in the La Ronge Belt.

Sampling and analysis of material from the Frontier, Box and Athona gold properties in the Goldfields – Beaverlodge area was continued this year and sampling of these localities has now been completed. The analytical work, mainly geochemistry and petrography, is continuing and should be completed by mid- to late-1989. This work will elucidate the metallogenesis of the auriferous "mine granites".

Also in the Beaverlodge region, a geochemical and mineralogical study of approximately 100 clastic samples of Martin Group and related formations is being conducted as a joint undertaking with P. Mazimhaka of the University of Saskatchewan. Partial funding of the geochemical analyses has been provided by Saskatchewan Energy and Mines. Results of Au, Pt and Pd analyses on some of these samples are discussed by Quirt (this volume).

The diabase dyke age-dating study reported above is part of a two-part project. The second study comprises a geochemical and mineralogical/petrographic investigation (Quirt and Mellinger, in progress), aimed at characterizing the Athabasca dykes for comparison with other Mackenzie swarm intrusions in the Canadian Shield. Geochemical and mineralogical analyses have been completed and the petrographic examinations are currently in progress. Final data analysis is expected to be completed by early 1989.

Initiated in 1987, the gold-related Waddy Lake granitoid project (see Quirt and Rees, 1987) has continued this year with geochemical analyses of approximately 400 samples and preparation of the accompanying thin sections. Whole rock x-ray diffraction mineralogical analyses have also been completed. Development of in-house rare earth element preconcentration procedures, prior to ICP-MS analysis for REE, is presently underway. The REE analyses, petrographic examinations and data analysis are to be completed in 1989.

3. References

Armstrong, R.L., Quirt, D.H. and Hoeve, J. (in prep.): Rb-Sr age-dating of diabase dykes in the Athabasca Basin, northern Saskatchewan; Sask. Res. Counc., Publ. R-855-3-A-88, 17p.

Mellinger, M., Quirt, D.H. and Hoeve, J. (1987): Geochemical signitures of uranium deposition in the Athabasca Basin of Saskatchewan, Canada; Uranium, v3, p187-209.

Quirt, D.H. and Mellinger, M. (1988a): Regional sandstone lithogeochemistry and uranium exploration in the Athabasca Basin; Geol. Assoc. Can./Mineral. Assoc. Can., Joint Annu. Meet., St. John's, Prog. Abstr., v13, pA102.

________ (1988b): Regional sandstone lithogeochemistry and uranium exploration in the Athabasca Basin; Sask. Res. Counc., Publ. R-855-1-D-88.

________ (in progress): Geochemical and petrographic characteristics of the diabase dykes in the Athabasca Basin, northern Saskatchewan; Sask. Res. Counc., Publ. R-855-2-A-88.

Quirt, D. and Rees, M. (1987): Current research in mineral deposits at the Saskatchewan Research Council; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rept. 87-4, p160-163.

Other Southern Studies

Geological Atlas of the Western Canada Sedimentary Basin

D.F. Paterson

Paterson, D.F. (1988): Geological Atlas of the Western Canada Sedimentary Basin; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

Geologists of Saskatchewan Energy and Mines are contributing to the Saskatchewan portion of the new Geological Atlas of the Western Canada Sedimentary Basin.

The departmental contributions are being made by four geologists. Doug Paterson is dealing with the basal clastic slice (Middle Cambrian through Ordovician). Fran Haidl is contributing to the Middle Ordovician through Silurian carbonate section. Dave Lane is tackling the Devonian Souris River Formation. Jim Christopher is handling both the Jurassic System and the Cretaceous Mannville Group. Papers in this volume by Paterson, Haidl and Christopher are all relevant to the Atlas project, as well as to more particular studies in the sedimentary geology of Saskatchewan.

The history, concept and rationale of the Atlas are outlined below as a direct quotation from *Geological Atlas of the Western Canada Sedimentary Basin: Annual Report 1987/88* (Grant D. Mossop, Atlas Project Manager, Alberta Research Council, Edmonton):

> The first "Atlas" – *Geological History of Western Canada* – was published by the Alberta Society of Petroleum Geologists in 1964 (McCrossan and Glaister, 1964). In the years since publication, the data base of wells in western Canada has increased many fold. The resolution and reliability of subsurface information has been subject to quantum advancements.
>
> Geological ideas on the stratigraphic and structural evolution of the basin have been revolutionized, not only by the advent of plate tectonic theory but also by the evolvement of comprehensive basin analysis techniques that embrace previously uncharted concepts of basin architecture, sedimentation patterns and facies relations, thermal/organic maturity, and regional hydrodynamic reconstruction.
>
> Today, there remains widespread demand for primary material on the regional geology of the Western Canada Sedimentary Basin, not only for reference in the early stages of new exploration plays or resource development projects in the energy industry, but also for multitudinous applications in academia and government. The production of a new and dynamic atlas is thus envisaged as a significant spur to increased effectiveness in all of the studies that rely on an atlas background. Rendered flexible by the availability of a readily updated computer data base, the new Atlas could serve as a standard reference for decades to come.
>
> Governments and scientific societies in western Canada have a very proud history of providing support for the nurturing of strong and equitable competition in the resource industries, through the provision of basic geological information. The creation and maintenance of the western Conservation Boards, with their universally accessible data banks and core examination facilities, are shining examples. The publications and technical conferences of the Canadian Society of Petroleum Geologists and other geoscientific associations are also widely held as providing essential stimulus to continued exploration and development success. Production of a new geological atlas of western Canada falls in the mainstream of this farsighted tradition.

Reference

McCrossan, R.G. and Glaister, R.P., eds. (1964): Geological History of Western Canada; Alberta Soc. Petrol. Geol., Calgary, 232p.

Geology and Natural Gas Production of the Upper Cretaceous Second White-Speckled Shale, Southwestern Saskatchewan

C.F. Gilboy

Gilboy, C.F. (1988): Geology and natural gas production of the Upper Cretaceous Second White-Speckled Shale, southwestern Saskatchewan; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

The informally named Second White-Speckled Shale forms the basal lithological unit of the Upper Colorado Group in the western Canadian interior. Cenomanian-Turonian in age, it is the approximate northern equivalent of the Greenhorn Formation of the western United States. In southwestern Saskatchewan, it currently commands much active interest from natural gas producers as, here and elsewhere in the northern Great Plains region (Figure 1), it is an important reservoir for sweet, dry, biogenic methane.

1. Lithological Description

In southwest Saskatchewan (Rge. 20W3 to 30W3, Townships 1 to 20), the Second White-Speckled Shale ranges in thickness from about 65 m in the south to about 13 m in the north. Throughout most of this area, three lithological subunits are readily distinguishable on geophysical logs (Figures 2 and 3) and in core which has been examined from 31 wells:

Subunit C:	Upper sandstones and shales with thin chalky limestone bands
Subunit B:	Middle shales and siltstones
Subunit A:	Lower sandstones and shales

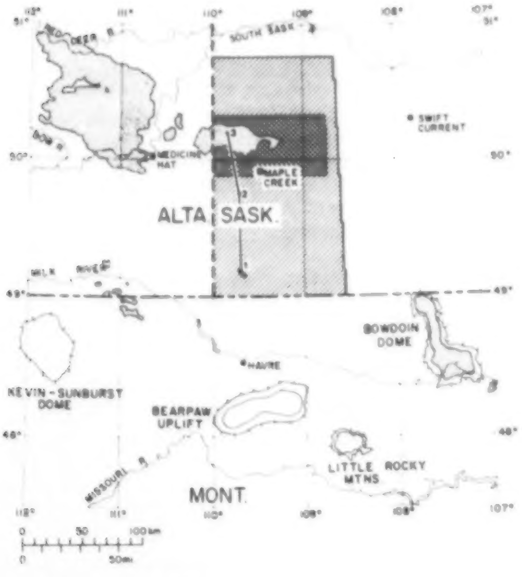


Figure 1 - Natural gas fields (stippled), Second White-Speckled Shale, northern Great Plains region, showing locations of: 1) the study area (diagonally hatched); 2) well 3 used to illustrate typical picks on geophysical logs in Figure 2; 3) south-north stratigraphic cross-section in Figure 3; 4) the area covered by the structure and cumulative gas-production map in Figure 4 (cross hatched); and 5) major tectonic uplifts (hachured).

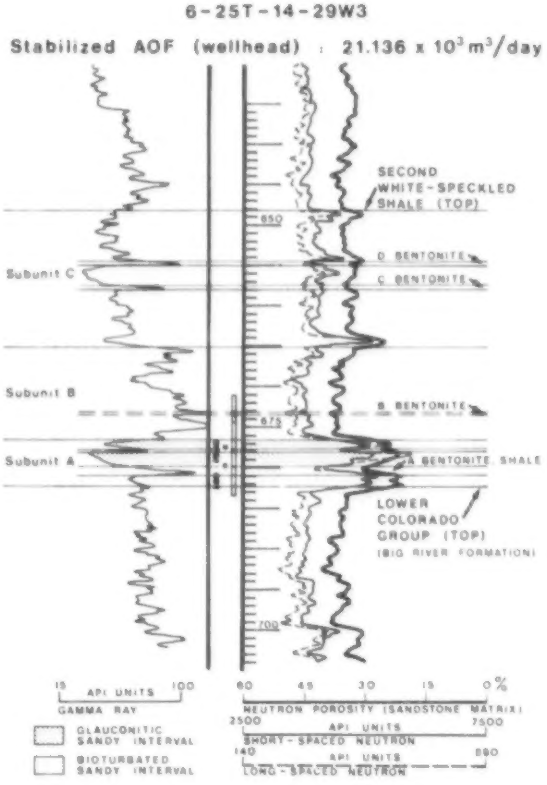


Figure 2 - Gamma ray-dual neutron porosity log of Second White-Speckled Shale showing: 1) picks for tops and bottoms of lithological Subunits A, B and C, and for bentonite layers A, B, C and D in Bigstick Gas Field (NCO Hatton 6-25T-14-29W3, K.B. 775.0 m; see Figure 1, well 3, for location); 2) perforated intervals (vertical dotted lines); 3) cored interval (vertical screened line; see also Plate 1); and 4) photograph locations (lower star, Plate 3C; upper star, Plate 3D). AOF, absolute open flow.

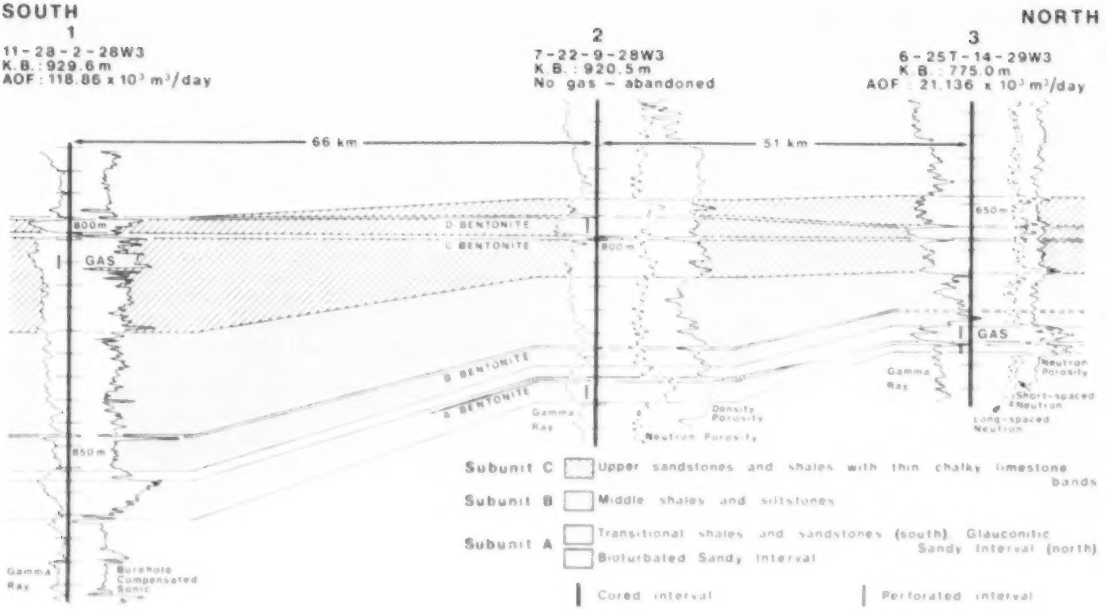

SOUTH
1
11-28-2-28W3
K.B.: 929.6 m
AOF: 118.86 x 10³ m³/day
2
7-22-9-28W3
K.B.: 920.5 m
No gas - abandoned
NORTH
3
6-25T-14-29W3
K.B.: 775.0 m
AOF: 21.136 x 10³ m³/day
66 km
51 km
800m
D BENTONITE
C BENTONITE
GAS
800 m
650m
GAS
B BENTONITE
A BENTONITE
850 m
Gamma Ray
Borehole Compensated Sonic
Gamma Ray
Density Porosity
Neutron Porosity
Gamma Ray
Neutron Porosity
Short-spaced Neutron
Long-spaced Neutron
Subunit C
Upper sandstones and shales with thin chalky limestone bands
Subunit B
Middle shales and siltstones
Subunit A
Transitional shales and sandstones (south) Glauconitic Sandy Interval (north)
Bioturbated Sandy Interval
Cored interval
Perforated interval

Figure 3 – South-north stratigraphic cross-section through Second White-Speckled Shale, southwestern Saskatchewan, showing main lithological subdivisions and gas-producing horizons in Senate (well 1) and Bigstick (well 3) Fields, using "C" bentonite as datum (see Figure 1 for location, and Plates 1, 2A, 3C and 3D for core photographs).

Bentonite layers up to about 0.5 m thick are present in all three subunits. Several of these layers are of regional extent and form isochronous marker horizons with distinctive log signatures (Figures 2 and 3).

a) Subunit A: Lower Sandstones and Shales

Subunit A is about 11 m thick in the south and 1.5 m in the north. Core examination of the contact between the basal subunit of the Second White-Speckled Shale and the underlying dark brown to dark grey, poorly fossiliferous and slightly pyritic shale of the Big River Formation (stratigraphic terminology after Simpson, 1982; see also Gilboy, 1987, Figure 1 for regional correlations) shows apparent conformity (Plate 1). Normally graded 0.5 to 20 cm (mostly 5 to 10 cm) thick beds of non-speckled noncalcareous Big River Formation argillites have bases made up of siltstone or very fine grained sandstone 0.1 to 0.5 cm thick. These merge upwards across 5 to 20 cm of section into thinly bedded, finely laminated and weakly bioturbated sandstones and shales (Plate 2A), here considered to constitute the base of the Second White-Speckled Shale. These thinly bedded rocks are rarely convoluted (Plate 2B), scoured (erosion surfaces have 1 to 2 cm of relief) and graded. Sand content and degree of bioturbation increase upwards. The visually estimated sand:shale ratio averages 1:1, but locally reaches 4:1. Bioturbation (especially *Terebellina*, but also possibly *Teichichnus* and *Arenicolites*) is sufficiently intense in places to destroy primary depositional fabrics (Plate 2C). This bioturbation characterizes the lower section of Subunit A, which is informally termed the "Bioturbated Sandy Interval". Sand grains are very fine, mostly in the range 62 to 88 μm but locally 88 to 125 μm, are generally rounded to subrounded or subangular in shape, and are well sorted. Glauconite (several percent), biotite and white mica (1 to 2 percent), lignitic plant material and fish debris are present in addition to quartz and clay minerals. Shell fragments are notably absent. Almost ubiquitously, the uppermost 20 to 30 cm of the Bioturbated Sandy Interval is cemented with calcite.

In the north, a pale grey regionally developed 1 to 20 cm thick bentonite (here termed the "A" bentonite) overlies the Bioturbated Sandy Interval and is, in turn, overlain by a 20 to 50 cm thick band of well-laminated shales and calcite-cemented sandstones little affected by bioturbation. South of about Township 10, the "A" bentonite lies a few centimetres below the top of the Bioturbated Sandy Interval, which here is capped by one or more 0.3 to 2.5 cm thick beds of coarse to very coarse sandstone (Plate 2D). The largest grains in these sandstone beds are 0.5 to 2.0 mm in diameter, are angular to subrounded fragments of dark chert along with fish bones and scales, and are supported in a matrix of very fine grained sand (88 to 125 μm).

The band of well-laminated shales and calcite-cemented sandstones found in the north is overlain by dark grey, slightly calcareous, nonbioturbated shale in which pelecypods (especially *Inoceramus*) and rare ammonites (Plate 3A) are well preserved. The shale ranges in thickness from a few centimetres to several metres. North of about Township 10, it is overlain by thinly

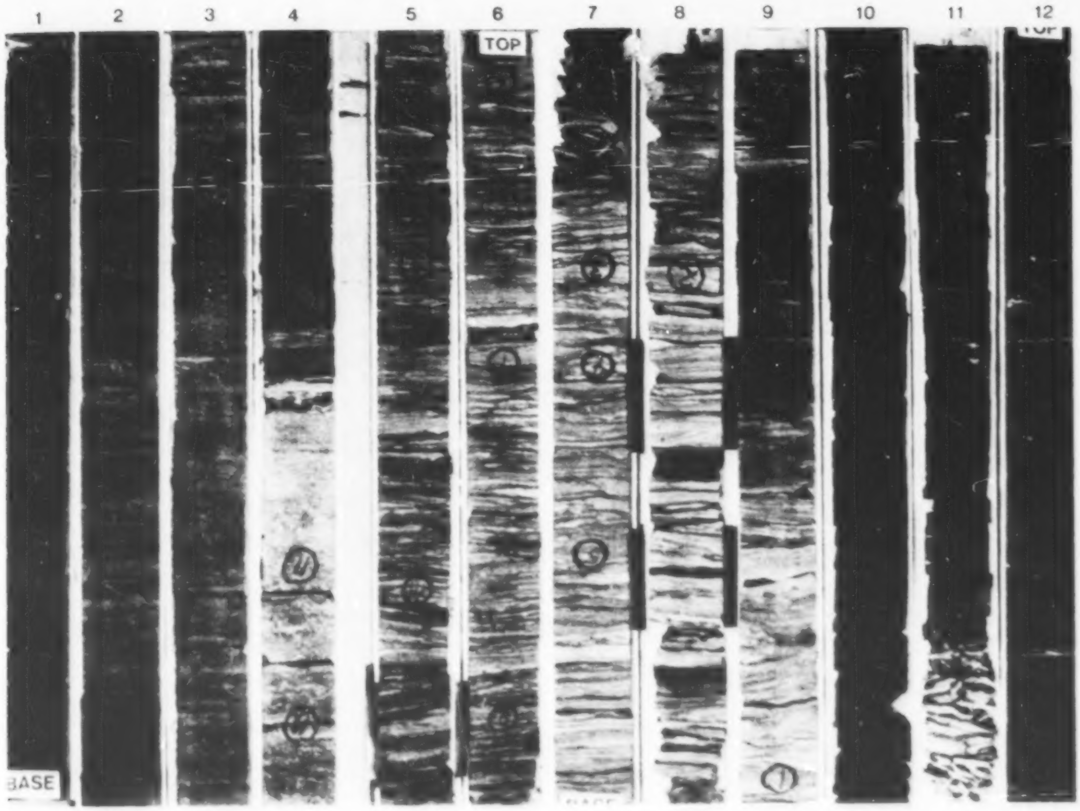


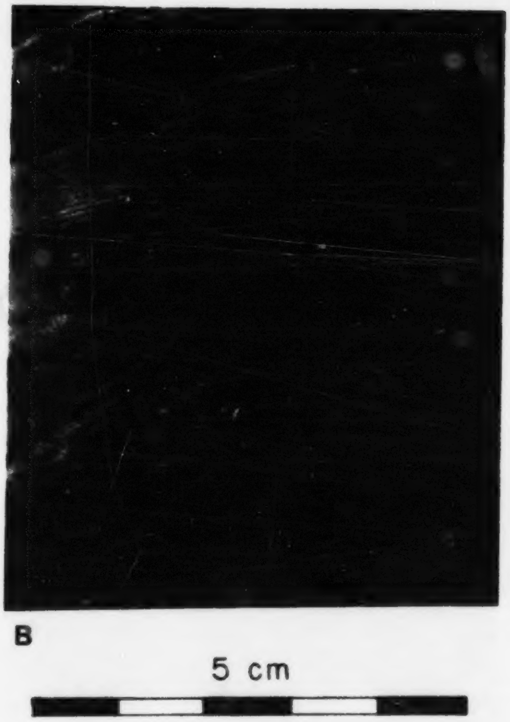
Plate 1 – Slabbed core showing uppermost shales of the Big River Formation (core container no. 1), a nearly complete section through Subunit A (the lower sandstones and shales, core containers nos. 1 to 9) and the base of Subunit B of the Second White-Speckled Shale (the middle shales and siltstones, core containers nos. 9 to 12), NCO Hatton 6-25T-14-29W3 (674.4 to 683.4 m below K.B.), southwestern Saskatchewan. About 10 cm of shale are missing from between the top of core container no. 4 and the base of container no. 5. See Plates 3C and D for detailed photographs.

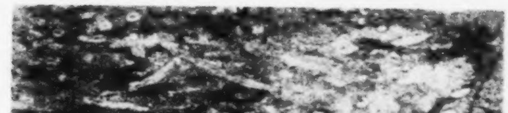
bedded, laminated, slightly bioturbated (*Arenicolites*[?], *Chondrites*; Plate 3B) and glauconite-rich (ca. 10 percent) sandstones and shales, informally termed the "Glauconitic Sandy Interval". Sandstone beds are commonly ripple cross-laminated (Plates 3A and B), especially towards the top of Subunit A. Rarely, normally graded beds and 1 to 2 cm deep scours are present. The visually estimated sand:shale ratio is generally about 2:1, with sand grains mostly rounded to subangular in shape, 88 to 125 μm across (in places 125 to 177 μm) and well sorted. These sandstones are typically moderate olive-green in colour because of their high glauconite content. Intergranular porosity is typically observed under the microscope except where infilled by interstitial clays or calcite cement (Plate 4A). The calcite cementation imparts a white colour to sandstone beds and is particularly common towards the top of Subunit A. Other subordinate components of the Glauconitic Sandy Interval include lignitic plant debris (about 1 percent), white mica and trace amounts of biotite and pyrite. In many places, a 2 to 20 cm thick layer of bentonite divides the interval into lower and upper sections. Ripple cross-lamination and calcite cementation are best developed in the upper section.

b) Subunit B: Middle Shales and Siltstones

Subunit B is poorly represented by core samples except where in contact with Subunit C. The subunit has been completely cored only where thinly developed – for example in Coseka Hatton 6-11-14-26W3 where it is only 8.7 m thick. The unit ranges from 8 m thick in the north to 30 m thick in the south. The transition from the Glauconitic Sandy Interval of Subunit A into shales with minor siltstones (silt:shale ratio commonly between 1:99 and 1:32) of Subunit B is gradational across about 0.5 m (Plate 1, core container no. 9). In its lowest metre, Subunit B is essentially noncalcareous, sparsely speckled, rarely convoluted, slightly pyritic and moderate grey to dark brown in colour. Fish debris is abundant. Upwards, several 1 to 5 cm thick bentonite beds herald increases in the carbonate content and, concomitantly, in the abundance of 0.5 to 1.0 mm diameter white specks. Normally graded beds, 0.1 to

A
5 cm


B
5 cm


C
5 cm

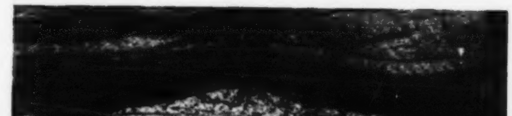

D
5 cm

Plate 2 – A) Weakly bioturbated (Terebellina, Arenicolites[?]), finely laminated, thinly bedded sandstones and shales near base of Subunit A, Second White-Speckled Shale, 0.5 m above contact with Big River Formation, at 834.2 m below K.B. in Canadian Roxy AEC Cypress Hills 7-22-9-28W3. B) Convolute bedding, possibly caused by slumping of the original sediments, and late subvertical fault with throw of about 1 cm, in weakly bioturbated (Terebellina), finely laminated and thinly bedded sandstones and shales of Subunit A, Second White-Speckled Shale, 1.0 m above contact with the Big River Formation at 663.5 m below K.B. Coseka Hatton 6-20-14-25W3. C) Intense bioturbation (Terebellina) regionally developed at the top of the lowermost sandy interval, Subunit A, Second White-Speckled Shale, 5.5 m above contact with Big River Formation at 917.5 m below K.B. in Canadian Roxy AEC Consul 10-3-5-26W3; compare with lower half of core container no. 4, Plate 1. D) Very coarse to coarse sandstones interbedded with very fine grained well-laminated sandstones and shales; dark chert grains up to 2 mm across are set in very fine sandy matrix; this unit directly overlies the Bioturbated Sandy Interval (Plate 2C) and is 7.5 m above contact with the Big River Formation, at 915.5 m below K.B. in Canadian Roxy AEC Consul 10-3-5-26W3.

3.0 cm thick, are numerous. They display horizontally laminated siltstone or very fine grained sandstone bases, and concentrations of white specks toward their argillaceous tops. Whole valves and fragments of *Inoceramus*, ranging from less than 1 cm to more than 8 cm across, are common, along with plant debris and fish remains (scales up to 7 mm in diameter, vertebrae ossicles that are mostly about 3 mm in diameter and spines). In places, shells are concentrated in one-valve-thick bands, most lying in a convex-upwards position. Euhedral biotite flakes up to 1 mm across are also commonly concentrated in specific laminae.

Within Subunit B is a regionally recognizable, pale lilac bentonite, 10 to 40 cm thick (here termed the "B" bentonite), which contains up to 2 percent fresh biotite flakes approximately 0.5 mm in diameter. A little above this marker horizon, a fine-grained pale grey and possibly concretionary 20 cm thick limestone is locally developed, cut by calcite-filled subvertical fractures up to 2 cm wide.

c) Subunit C: Upper Sandstones and Shales with Thin Chalky Limestone Bands.

Subunit C is about 25 m thick in the south and thins northwards to about 3.5 m. South of about Township 7, it is predominantly composed of sparsely speckled, thinly interbedded shales and laminated sandstones (sand:shale ratio about 2:1 in sandiest sections, 1:6 in shaliest zones) in which scouring, load-casting and normally graded beds (less than 1 cm to about 4 cm thick) are commonly well displayed (Plates 4B to D). The rocks are noncalcareous to moderately calcareous, and are locally slightly bioturbated, mainly by a subhorizontally burrowing organism, probably *Chondrites*. Most sandstone beds are glauconitic and consequently olive green in colour. They contain well-sorted, well-rounded to subangular quartz grains 62 to 88 μm in diameter. *Inoceramus* fragments tend to be concentrated at the base of sandy layers. The top 3 to 5 m of Subunit C are made up of highly calcareous, richly speckled, thinly bedded (0.1 to 1.0 cm) shales (approximately 90 percent) and very fine grained sandstone (approximately 10 percent) in which up to three 5 to 25 cm thick bands of fine-grained concretionary limestone are locally present. Within these limestones, sedimentary laminae and shelly layers are generally preserved. Fish debris is abundant, as are *Inoceramus* fragments. Crushed *Baculites* up to about 5 cm long are rare. Several bentonite beds also occur near or at the top of Subunit C; of these, two (here termed the "C" and "D" bentonites) are regionally recognizable. The "C" bentonite, the lower of the two, is a pale lilac 25 to 50 cm thick layer, up to 2 percent of which is composed of 1 to 2 mm diameter euhedral biotite flakes. Core intersecting the "D" bentonite has not been identified.

In the northern part of the study area (e.g., Coseka Hatton 6-11-14-26W3), Subunit B grades upwards into highly calcareous shales of Subunit C containing 1 to 4 cm thick white calcite-cemented sandy layers (sand:shale ratio 1:6) in which fish remains and disseminated pyrite are common. Calcispheres 0.05 to 0.1 mm across are locally preserved. The shales are profusely speckled, mid-grey to brown and essentially nonbioturbated. Normally graded beds are clearly developed in some places, but in others are not obviously recognizable, especially where the sand:shale ratio is less than 1:99. The uppermost metre of Subunit C is made up of very calcareous interstratified shales and weakly pyritic chalky limestone layers and lenses up to 3 cm thick (limestone:shale ratio 1:6 to, rarely, 1:1.5) in which calcispheres, nannofossils (Plate 5A) and other as-yet-unidentified microfossils (Plate 5B) are preserved. Fish remains and *Inoceramus* fragments and whole valves are abundant, but lignitic plant debris is generally scarce. Some carbonate layers are ripple cross-laminated; most contain rounded to subangular sand grains 88 to 125 μm across (rarely 125 to 177 μm). Several 4 to 7 cm thick bentonite beds are present.

The Second White-Speckled Shale is overlain by dark to moderate grey, horizontally laminated, nonbioturbated, noncalcareous shales which contain numerous 1 to 3 cm thick normally graded beds and which are assumed to be basal rocks of the Carlile Shale, a widely recognized lithostratigraphic unit in the western United States (see Gilboy, 1987, Figure 1). Abundant *Inoceramus* shell fragments, as well as rare articulated valves, some strongly ribbed ammonites 1 or 2 cm in diameter, and other organic material such as fish debris are commonly concentrated in specific layers.

2. Depositional Environment

a) Subunit A

Rocks of Subunit A are typical of the mud-dominated to sand-dominated subfacies of the heterolithic shallow marine siliciclastic lithofacies described by Johnson (1978). At the base, a mud-dominated to mixed subfacies deposit appears to be present throughout the study area, and is particularly distinctive because of intense bioturbation in its topmost levels by a restricted infauna (mainly *Terebellina*). Grading, scouring, horizontal

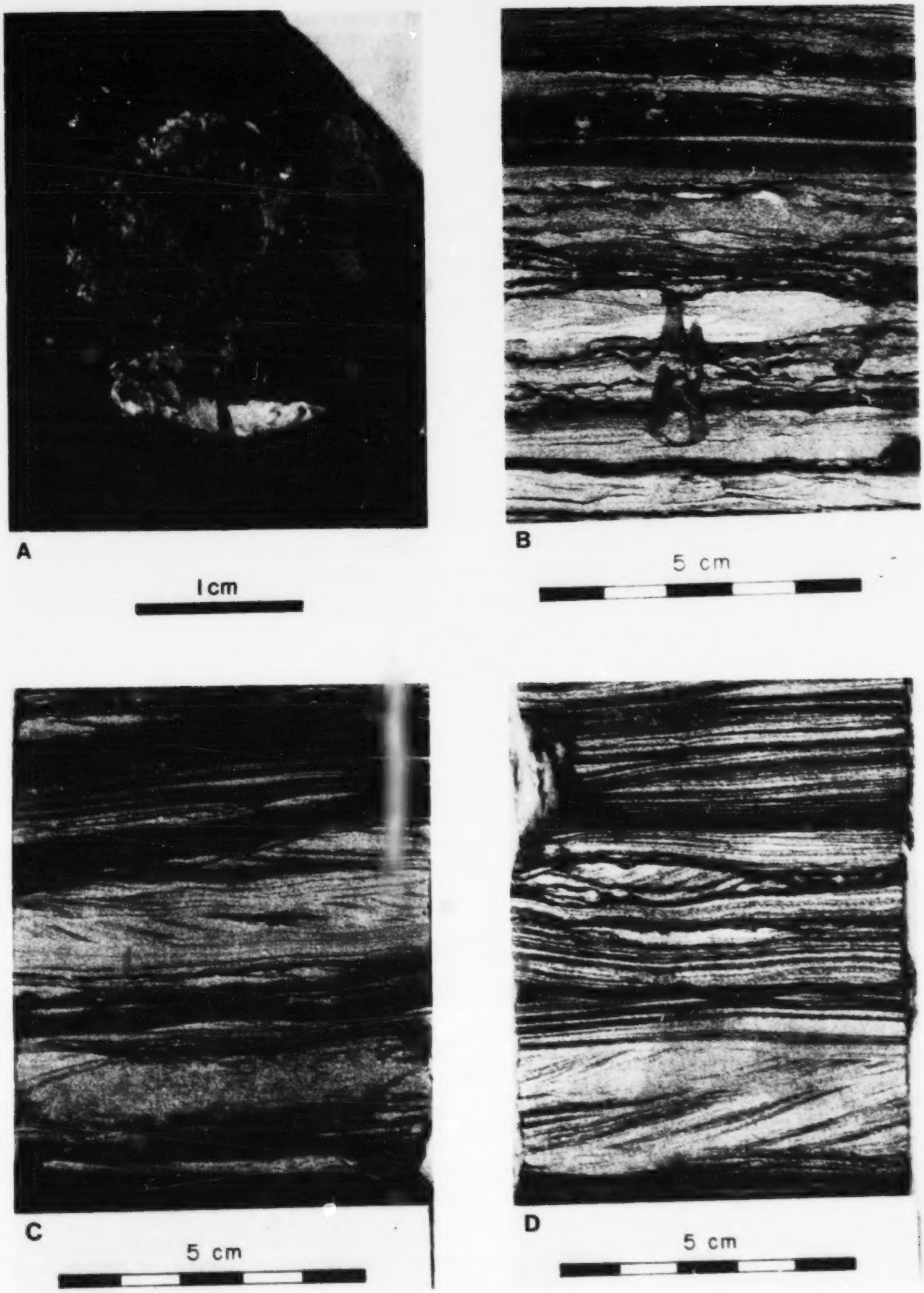

A
1 cm
B
5 cm
C
5 cm
D
5 cm

Plate 3 – A) Well-preserved ammonite, as yet unidentified, from shale bed separating the two sandy intervals of Subunit A, Second White-Speckled Shale, 5.5 m above contact with Big River Formation, at 659.0 m below K.B. in Coseka Hatton 6-20-14-25W3. B) Thinly bedded, finely laminated, weakly bioturbated (Arenicolites(?), Chondrites) glauconite-rich sandstones and shales of the higher of the two Subunit A sandy intervals, Second White-Speckled Shale, 4.4 m above contact with Big River Formation at 661.9 m below K.B. in NCO Hatton 6-25T-14-30W3. C) Thinly bedded, ripple cross-laminated beds of the Glauconitic Sandy Interval of Subunit A, Second White-Speckled Shale, showing scouring and, at the top of the picture, normal grading, 2.7 m above contact with Big River Formation, at 680.3 below K.B. in NCO Hatton 6-25T-14-29W3; see Figure 2 and Plate 1 for location of this photo, at base of core container no. 5. D) Thinly bedded, ripple cross-laminated, calcite-cemented beds of the Glauconitic Sandy Interval of Subunit A, Second White-Speckled Shale, 5.3 m above contact with Big River Formation, at 677.7 m below K.B. in NCO Hatton 6-25T-14-29W3; see Figure 2 and Plate 1 for location of this photo, central part of core container no. 8.

Plate 4 (overleaf) – A) SEM photomicrograph of clay-coated clastic grains and intergranular calcite cement, near top the Glauconitic Sandy Interval of Subunit A, Second White-Speckled Shale, 9.5 m above contact with Big River Formation, at 678.7 m below K.B. in Coseka Hatton 11-5-14-25W3. B) Thinly bedded, finely laminated and weakly bioturbated sandstones and shales of Subunit C, Second White-Speckled Shale, showing scouring, normal grading, load casting and disruption of sandy laminae due to dewatering of shale, 56.1 m above contact with Big River Formation, at 866.6 m below K.B. in Canadian Roxy AEC Consul 10-3-5-26W3; arrow points to Inoceramus shell fragments at base of scourfill. C) Thinly bedded, finely laminated and normally graded sandstones, siltstones and shales of Subunit C, Second White-Speckled Shale, 58.8 m above contact with Big River Formation, at 863.9 m below K.B. in Canadian Roxy AEC Consul 10-3-5-26W3; arrow points to Inoceramus shell fragment at the base of a graded bed. D) Normally graded, moderately calcareous sandstones, siltstones and shales near top of Subunit C, Second White-Speckled Shale, showing Bouma (1962) divisions D and E, 60.2 m above contact with Big River Formation, at 862.5 m below K.B. in Canadian Roxy AEC Consul 10-3-5-26W3; bed bases are slightly erosive.

parallel lamination and rare convolute bedding indicate that the original sediments were distal offshore shelf deposits in which sands were mainly transported by storm-surge induced, low-density turbidity currents. Sedimentation rates were relatively slow, permitting extensive reworking by small *Terebellina*, an organism characteristic of offshore deposits (Chamberlain, 1978). The presence of the regionally developed "A" bentonite bed at or within a few centimetres of the top of the bioturbated rocks implies that they are essentially isochronous.

Ammonites are preserved in the shale separating the bioturbated strata from overlying deposits (north of Township 9) of mixed to sand-dominated subfacies, suggesting that the rocks of Subunit A are of open marine origin.

Weakly bioturbated sandstones in the mixed to sand-dominated subfacies are glauconite rich, commonly ripple cross-laminated and, although very fine grained, slightly coarser than sandstones in the intensely bioturbated interval. Cross-laminations, probably current generated, tend to be unidirectional. Lithologically, this higher sandy interval in Subunit A closely resembles Upper Cretaceous shelf sand bodies described from other areas, such as the Shannon Sandstone of Wyoming (Spearing, 1976). The geometry of the two sandy intervals in Subunit A is not known in detail, but stratigraphic cross-sections prepared by the author show that the lower interval is a sheet-like body which thins from south to north. In contrast, the upper sandy interval appears to be elongate, with a north-south width of some 50 km, an east-west length of more than 65 km and a central maximum thickness of about 5 m. The original sediments appear to have been relatively rapidly deposited in storm-dominated open-shelf conditions.

b) Subunit B

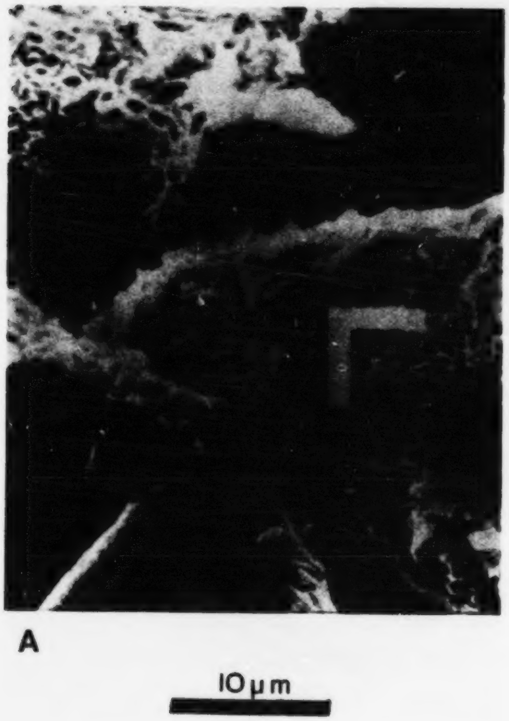
Rocks of Subunit B are slightly pyritic, lack bioturbation, contain a severely restricted epifauna (almost exclusively *Inoceramus*) and have numerous graded beds with a low silt:shale ratio. They probably originated as bituminous to restricted mud facies (Johnson, 1978) shelf deposits. White specks, made up largely of coccoliths and coccospheres, are abundant in the shales and presumably accumulated along with suspended clay particles during quiescent interstorm periods.

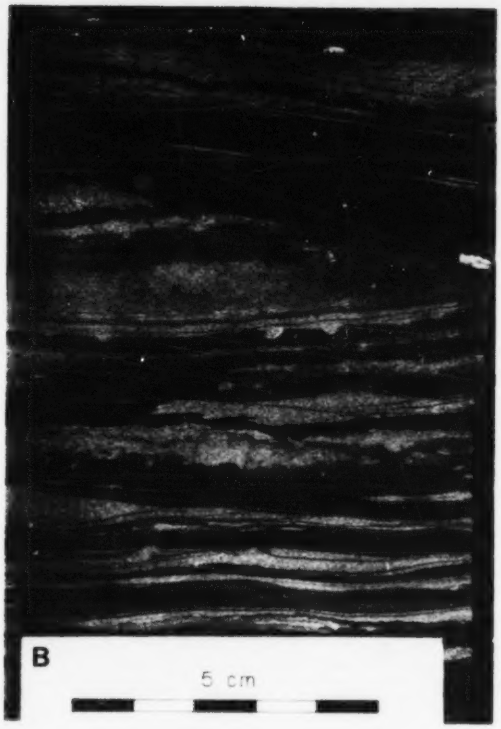
c) Subunit C

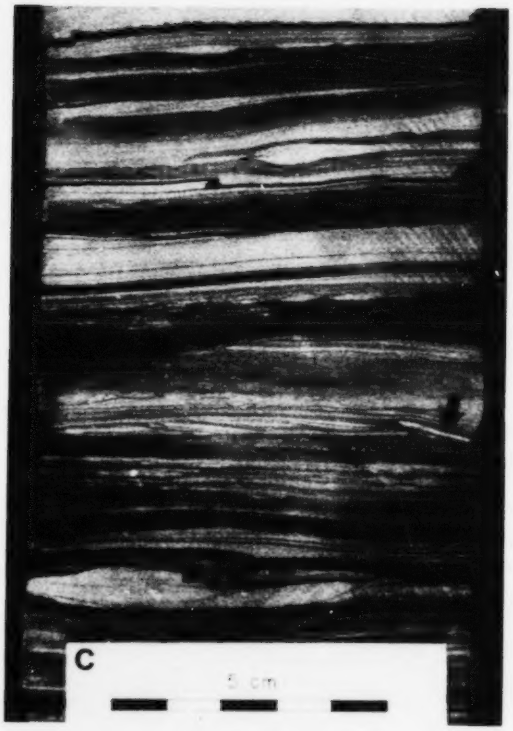
Rocks of Subunit C show a marked increase in their sand:shale ratios over those of Subunit B, but, like them, were apparently deposited in an outer shelf environment largely from storm-generated turbidity currents. Quartz grains are abundant in thin ripple cross-laminated chalky limestone beds, which are presumed also to have originated as storm deposits. Lack of intense bioturbation suggests that the sedimentation rate was high compared with that of the Bioturbated Sandy Interval at the base of Subunit A, or that within-sediment conditions were unsuitable for supporting an abundant or diverse infauna. Regionally developed bentonites "C" and "D" are situated, respectively, 4 m below and at the top of Subunit C in the south (e.g., 11-8-2-28W3), but 13 m and 11 m below the top in the north (e.g., 6-31-13-23W3). This is probably because the top of the Second White-Speckled Shale is diachronous, being younger in the north than in the south (Figure 3).

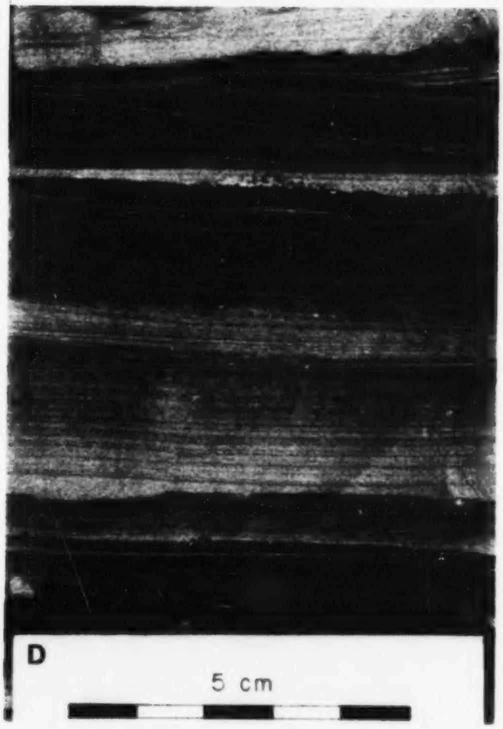
3. Structure

Structure contours on the top of the Second White-Speckled Shale in the northern part of the study area (Figure 4) show a gentle east-southeast regional dip which steepens from 0.05° (about 7 m per 10 km) in the western six townships to 0.1° (about 17 m per 10 km) in the eastern three townships. The steepest dips (0.5° or about 88 m per 10 km) occur in the southeast, on the northern rim of a basin-shaped tectonic feature.


A
10 µm


B
5 cm


C
5 cm


D
5 cm

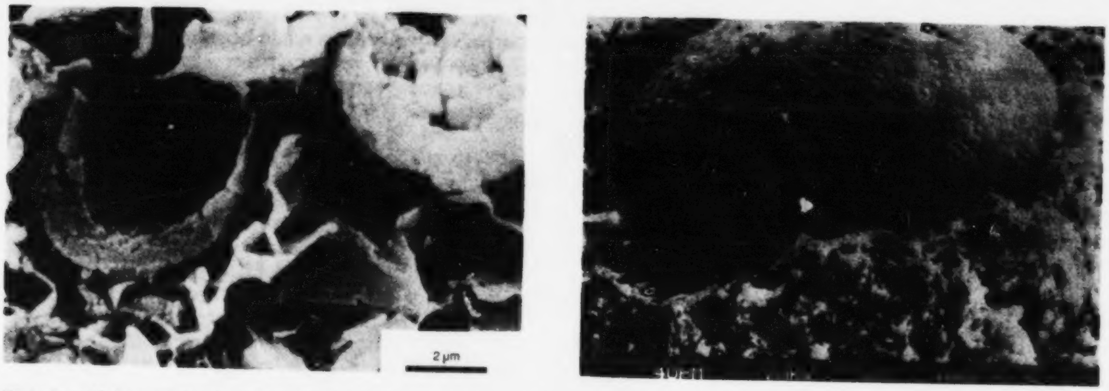


Plate 5 – A) Scanning electron micrograph showing calcareous nannofossils, currently unidentified, from very calcareous speckled shales interbedded with 1 to 5 mm thick flaser-bedded impure chalky limestones near top of Subunit C, Second White-Speckled Shale, 31.2 m above contact with Big River Formation, at 701.5 m below K.B. in OIL 85 Hatton 6-9-12-26W3. B) Scanning electron micrograph of currently unidentified microfossil, from same sample as Plate 5A.

Superimposed upon the regional dip are shallow open northwest-trending anticlines and synclines which, for the most part, plunge southeastwards but locally plunge northwestwards to produce domes and basins of generally limited areal extent and with closure reliefs typically less than 10 m. These plunge reversals in part reflect cross-folding about northeast- to east-northeast-trending axes, locally subparallel to the hinge of the Sweetgrass – North Battleford Arch (Figure 5).

Partial to complete dissolution of Devonian Prairie Evaporite beds, which underlie younger strata in most

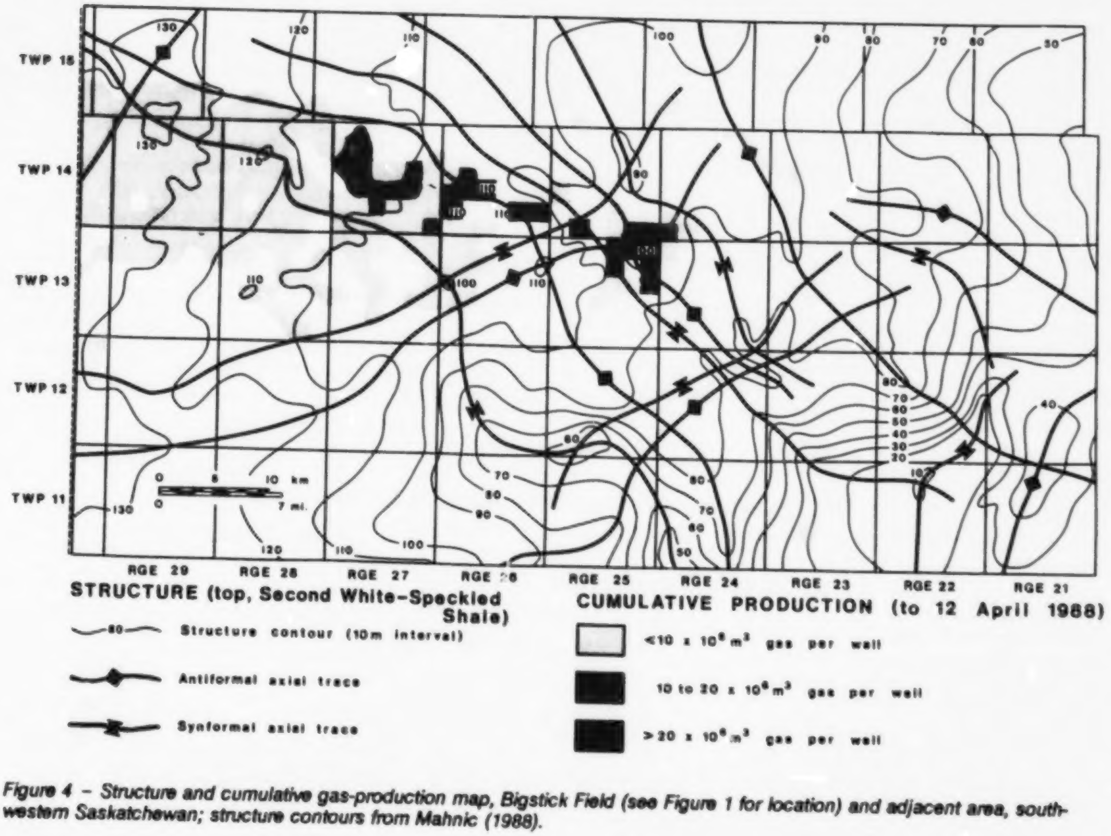

TWP 15
TWP 14
TWP 13
TWP 12
TWP 11
RGE 29
RGE 28
RGE 27
RGE 26
RGE 25
RGE 24
RGE 23
RGE 22
RGE 21
0 5 10 km
0 7 mi.
STRUCTURE (top, Second White-Speckled Shale)
80 Structure contour (10m interval)
Antiformal axial trace
Synformal axial trace
CUMULATIVE PRODUCTION (to 12 April 1988)
<10 x 10⁶ m³ gas per well
10 to 20 x 10⁶ m³ gas per well
>20 x 10⁶ m³ gas per well

Figure 4 – Structure and cumulative gas-production map, Bigstick Field (see Figure 1 for location) and adjacent area, southwestern Saskatchewan; structure contours from Mahnic (1988).

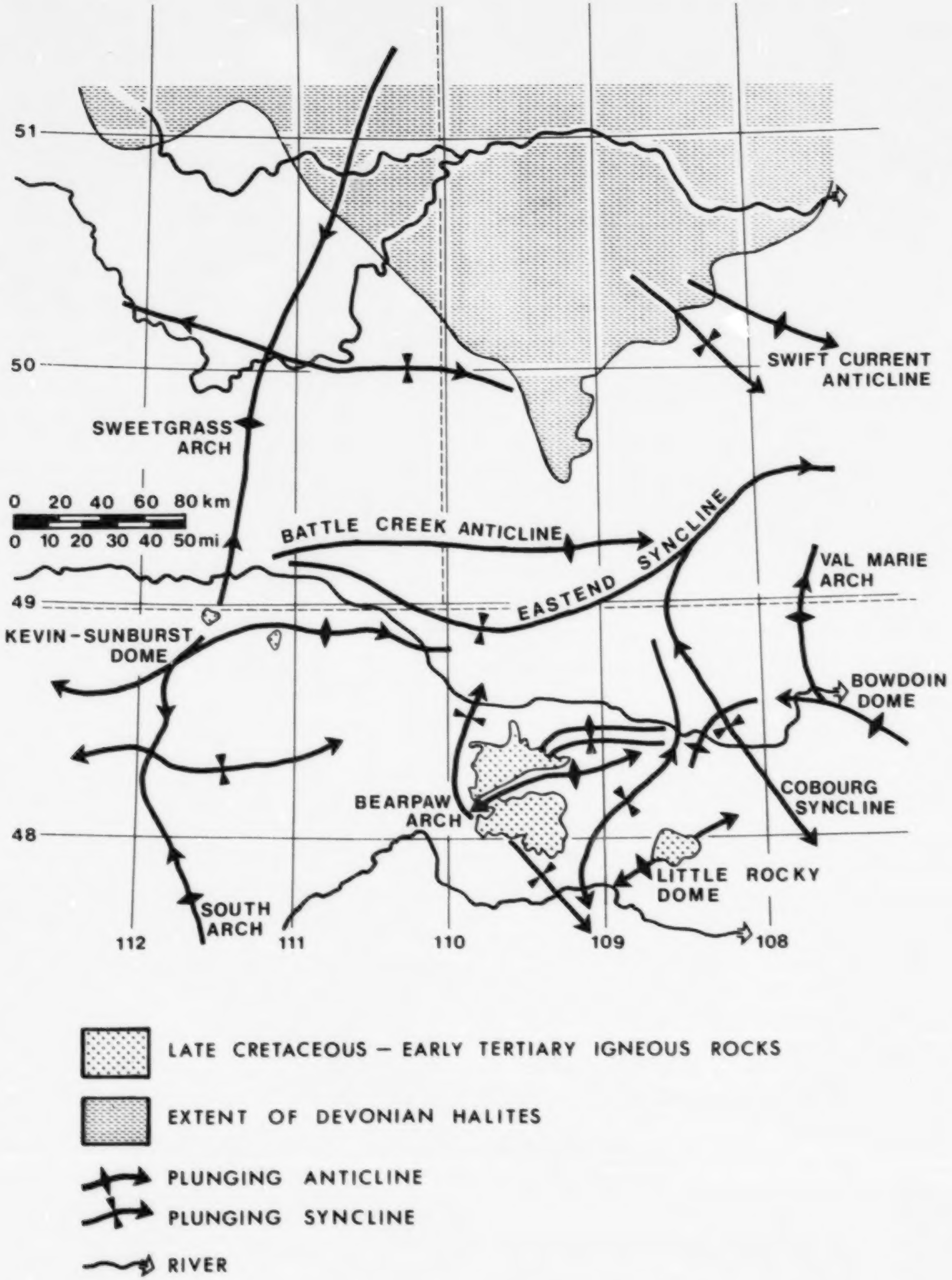

51
50
49
48
112
111
110
109
108
SWEETGRASS ARCH
0 20 40 60 80 km
0 10 20 30 40 50 mi
SWIFT CURRENT ANTICLINE
BATTLE CREEK ANTICLINE
EASTEND SYNCLINE
VAL MARIE ARCH
KEVIN-SUNBURST DOME
BOWDOIN DOME
COBOURG SYNCLINE
BEARPAW ARCH
LITTLE ROCKY DOME
SOUTH ARCH
LATE CRETACEOUS – EARLY TERTIARY IGNEOUS ROCKS
EXTENT OF DEVONIAN HALITES
PLUNGING ANTICLINE
PLUNGING SYNCLINE
RIVER

Figure 5 - Major regional folds, northern Great Plains region.

of the area shown in Figure 4, may have contributed genetically to deformation of the surface of the Second White-Speckled Shale, in particular to its steepening dip in the east towards the presently mapped limit of Prairie Evaporite (Figure 5; see also Lane (1987) for accurate and more detailed delineation of this edge).The northwest-trending folds may be due to preferential dissolution of evaporites along northwest-trending fractures, which is a common orientation in the northern Great Plains region (Shurr, 1982; Brown and Brown, 1987).

Tectonic structures are rarely observed in core, where they are limited to high-angle faults with small displacement (Plate 2B) or moderately dipping slickensided fracture surfaces with unknown displacement (Plate 1, container no. 10).

4. Natural Gas Production

Commercially viable quantities of natural gas were discovered in the Second White-Speckled Shale of southwestern Saskatchewan in 1980. The discovery well of what is currently known as the Bigstick Field was Coseka et al. Hatton 10-17-14-26W3 (B. West, pers. comm.). Major production from the Bigstick Field began in 1984 and has since risen steadily (Figure 6) to the extent that it now approaches Milk River Formation and comingled Milk River Formation – Medicine Hat Sandstone total yields, and is substantially greater than that from the Medicine Hat Sandstone alone.

The reservoir rocks for Bigstick natural gas are the two sandy intervals of Subunit A, Second White-Speckled Shale, of which the higher Glauconitic Sandy Interval is the more productive.

The main hydrocarbon trapping mechanism is stratigraphic. Highest gas production is from those parts of the Bigstick Field where the Glauconitic Sandy Interval is most thickly developed, most permeable and most porous (Table 1). Field boundaries appear to be largely defined in the north by occlusion of the Glauconitic Sandy Interval and in the south by decreased permeability and porosity of the same interval.

Structure may also have a small controlling influence on gas accumulation and productivity, as the majority of highest producing wells in the Bigstick Field occupy the crests of shallow domes in Ranges 25 and 26, Townships 13 and 14 (Figure 4).

Selected physical parameters pertinent to the Bigstick Field and the much smaller Senate Field are listed in Table 2.

The Senate Field, approximately 110 km south of the Bigstick Field, is not connected to the major gas-pipeline network, but has been developed to supply gas to the town of Consul. Three wells have been perforated where they intersect noncalcareous, thinly bedded, normally graded sandstones and shales of largely turbiditic origin some 8 m below the top of Subunit C. The productive reservoir rocks appear to have a higher sand:shale ratio (2:1) than in nearby nonproductive wells (less than 1:1), but structure might also be an important control on gas concentration, as the Senate Field is situated at or close to the crest of the Battle Creek Anticline (Figure 5). Only one well (7-4-3-28W3) has been producing substantial quantities of gas to date (close to 400×10^3 m^3), although flow rates of close to 25×10^3 m^3/day are allowed for this and the other two wells. Natural gas in this field was initially encountered in 1971 in a drillstem test run in the UBR Noel Senate 11-28-2-28W3 well.

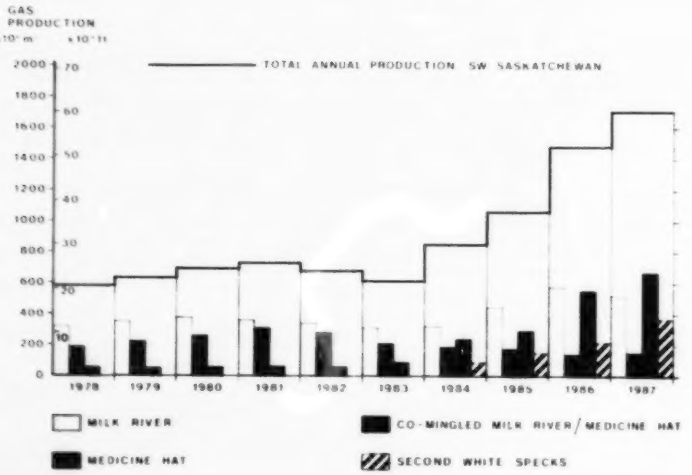


Figure 6 – Total annual gas production, 1978-1987, southwestern Saskatchewan.

As with Upper Cretaceous shallow gas accumulations elsewhere in the northern Great Plains region, drilling methods and completion techniques are critical if extensive reservoir damage is to be avoided during pool development. The majority of producing wells in the Bigstick Field have been drilled with 3 percent KCl fluids to inhibit the swelling of water-absorbent clay minerals (smectite-illite) present throughout most Upper Colorado Group and Lower Montana Group rocks, including the gas-bearing sandy intervals. After the hole-casing has been inserted, it is perforated using a shot-density of generally 3 to 7 per metre. Reservoir rocks are subsequently fractured hydraulically by pumping 20,000 to 60,000 kg of 8/12 ± 10/20 ± 20/40 mesh sands (most commonly 25,000 kg of 20/40 mesh) slurried in 35 to 50 m^3 (most commonly about 40 m^3) of gelled 3 percent KCl water. This is sometimes heated and contains additives such as clay stabilizers, cross-linked gels and CO_2 (50 to 100 m^3/m^3 slurry, generally about 60 m^3/m^3). Up to 1,000 litres of 15 percent HCl is sometimes used to

Table 1 – Permeability and Porosity Values Obtained from Pay Zone Core Plugs (and their Stratigraphic Equivalents), Bigstick and Senate Gas Fields and Intervening Areas, Southwestern Saskatchewan

Area	Well (Location)	AOF Data[1] (10^3 m^3/day)	Net Pay (m) Subunit A Biotur-bated	Net Pay (m) Subunit A Glauc-onitic	Net Pay (m) Subunit C	Average[2] Permeability (md)	Range of Permeability in Pay Zone (md)[3]	Average[2] Porosity (percent)	Range of Porosity Values in Pay Zone (percent)[3]
Bigstick Field	11-5-14-25W3[4]	109.023 (sandface)	2.0	3.4	–	9.16	2.12 – 233.1	23.6	17.3 – 33.7
	6-25T-14-29W[5]	21.136 (wellhead)	1.5	3.3	–	3.13	1.9 – 155.7	20.0	13.3 – 26.3
	6-25T-14-30W3[6]	5.252 (wellhead)	2.5	1.4	–	1.12	0.2 – 10.5	N/A	1.7 – 22.3
South of Bigstick Field	6-5-13-29W3	–	2.5	1.0	–	0.43	0.2 – 8.9	14.0	6.0 – 19.8
	7-22-9-28W3[7]	–	1.75	absent	–	0.59	0.1 – 3.1	15.2	10.0 – 19.1
Northeast of Senate Field	10-3-5-26W3[8]	–	–	–	3.0	1.7	0.7 – 43.5	13.8	5.4 – 21.6
		–	4.7	absent			0.3 – 5.61		1.5 – 16.8
Senate Field	11-28-2-28W3	118.86 (sandface)	–	–	3.05	not available	9.8 – 23.5	not recorded	not recorded
		–	6.4	absent	not cored	not cored	not cored	not cored	

[1] stabilized absolute open flow, where measured
[2] harmonic mean
[3] from core plugs
[4] see Plate 4A
[5] see Plates 1, 3C and 3D
[6] see Plate 3B
[7] see Plate 2A
[8] see Plates 2C, 2D, 4B, 4C and 4D

clean the perforations, in which case an iron-chelating agent must also be added to prevent precipitation in pore spaces of ferric hydroxide gel, produced from reaction of the acid with pyrite. Fracture-fluid pumping rates range from 4 to 9 m^3/minute.

The approximate cost of drilling, casing and completing a gas well in Bigstick Field is Can $150,000 . Additional expenditure of about Can $30,000 is required for equipment and labour to connect the well into the existing network of pipelines. The pool development threshold in the vicinity of the Bigstick Field is total daily production of 140 x 10^3 m^3 in an area of 4 to 5 sections.

5. Acknowledgements

I am grateful to Dean Potter of Mark Resources Inc. and John MacDonald of SabreWest Oil and Gas Ltd. for critically reviewing the text of this contribution. Dean further assisted me by supplying data used in the final paragraph.

Table 2 – Some Selected Physical and Chemical Parameters for the Bigstick and Senate Gas Fields

	Bigstick Field	Senate Field
Depth	650 m	810.0 m
Spacing unit	256 hectares	
Average temperature	26°C	
Average porosity	20 percent	
Average permeability	1 to 10 md	
Average net pay	4.0 m	3.0 m
Average connate water saturation	30 percent	
Recovery factor	65 percent	
Average reservoir pressure	6100 kPa	
Average AOF rates ($10^3 m^3$/day)	20 to 115	
Heating value	36 MJ/m^3	
Methane	94.5 percent	94.0 percent
Ethane	0.5 percent	0.4 percent
Nitrogen	5.0 percent	5.3 percent
Initial gas in place	11.3×10^9 m^3	
Recoverable gas in place	8×10^9 m^3	
Average per section reserves	58×10^8 m^3	
Average daily production per well	20-28 $\times 10^3$ m^3	

6. References

Bouma, A.H. (1962): Sedimentology of some Flysch Deposits: A Graphic Approach to Facies Interpretation; Elsevier, Amsterdam, 168p.

Brown, D.L and Brown, D.L. (1987): Wrench-style deformation and paleostructrual influence on sedimentation in and around a cratonic basin; *in* Longman, M.W. (ed.), Williston Basin: Anatomy of a Cratonic Oil Province; Rocky Mountain Assoc. Geol., Denver, p57-70.

Chamberlain, C.K. (1978): Recognition of trace fossils in cores; *in* Basan, P.B. (ed.), Trace Fossil Concepts; Soc. Econ. Paleon. Mineral., Short Course 5, p119-166.

Gilboy, C.F. (1987): Aspects of the regional geological framework of low-permeability shallow gas reservoirs in Upper Cretaceous strata (Colorado and Montana Groups), southwestern Saskatchewan; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p199-213.

Johnson, H.D. (1978): Shallow siliciclastic seas; *in* Reading, H.C. (ed.), Sedimentary Environments and Facies; Blackwell Scientific Publ., London, p207-258.

Lane, D.M. (1987): Subsurface carbon dioxide in Saskatchewan: sources and potential use in enhanced oil recovery; Sask. Energy Mines, Open File Rep. 87-2, 40p.

Mahnic, P. (1988): Structural contours on the Second White-Speckled Shale, Hatton area; Sask. Energy Mines, Map K-14(S)-3.

Shurr, G.W. (1982): Geological significance of lineaments interpreted from Landsat images near the northern Black Hills; *in* Christopher, J.E. and Kaldi, J. (eds.), Fourth International Williston Basin Symposium; Sask. Geol. Soc., Spec. Publ. 6, p313-320.

Simpson, F. (1982): Sedimentology, paleoecology and economic geology of Lower Colorado (Cretaceous) strata of west-central Saskatchewan; Sask. Energy Mines, Rep. 150, 183p.

Spearing, D.R. (1976): Upper Cretaceous Shannon Sandstone: an offshore, shallow-marine sand body; Wyoming Geol. Assoc. Guidebook, 28th Field Conf., p65-72.

Note on an Upper Jurassic Section in Southeastern Saskatchewan and its Relationship to Adjacent Regions

J.E. Christopher[1]

Christopher, J.E. (1988): Note on an Upper Jurassic section in southeastern Saskatchewan and its relationship to adjacent regions; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

The Upper Jurassic of Saskatchewan is represented by the Vanguard Group of marine shales and sandstones (Milner and Thomas, 1954; Francis 1956, 1957; Milner and Blakslee, 1958). The Vanguard was divided into three members now formalized (o-y)[2] as the Rush Lake Shale, Roseray Formation and Masefield Shale (Christopher, 1974). Initially these formations were faunally dated as Callovian, Callovian-Oxfordian and Oxfordian respectively (Brooke and Braun, 1972), but are now dated as Bathonian, Callovian-Oxfordian and Oxfordian (Imlay, 1980; Poulton, 1984).

There was also a consensus that the Vanguard Group is a correlative of the Rierdon and Swift Formations of Montana (Cobban, 1945; Imlay, 1945, 1947; Imlay et al., 1948). More specifically, the Rush Lake or Lower Vanguard was correlated with the Rierdon Shale, and the Masefield Shale or Upper Vanguard with the lower part of the Swift Formation (i.e., the Swift Shale). The medial Roseray Formation of southwestern Saskatchewan presented a dilemma as to whether or not it was Swift (Francis, op. cit., Springer et al., 1964) or was divided into Rierdon and Swift (Peterson, 1957). Milner and Blakslee (op. cit.), merely observing that the Middle Vanguard sandstones appeared in neither the Rierdon nor Swift of the type Sweetgrass arch region, left the question unanswered.

Christopher (op. cit.), on the basis of work by Nolte (1967), showed the Roseray Formation to be a sandy facies of a Rierdon shale lithotope by virtue of westerly to southeasterly offlapping clinobeds.

The superjacent Mannville Group rests on a conspicuous erosion surface generally recognized as the base of the Cretaceous system. Initially two formations were distinguished (o-y): Cantuar and Pense (Price, 1963; Maycock, 1967). A third, basal to the group, was separated out by Christopher (ibid.) who named it the Success Formation. Because it is unconformity bounded, the Success varies from 0 to 45 m in thickness. In general, the Success Formation overlies the Masefield Shale, but northward into the Swift Current oilfield district the basal contact intersects the Roseray Formation. Two members are identified (o-y): S_1 and S_2.

The S_1 member consists of bedding groups 0.5 to 6 m thick, comprising quartzose very fine grained grey-white to light grey kaolin-indurated sandstone, intermixed and laminated with quartzose coarse-grained carbonaceous lavender-grey to black siltstone with sparse to abundant layers of sphaerosiderite. Locally, the carbonaceous beds are weakly bioturbated, contorted, brecciated, microfaulted and glauconitic.

The S_2 member overlies S_1 disconformably and features coarser grade sizes of kaolin-indurated quartzose sandstone. Bimodality of grade size and trough-crossbedded sequences fining upward from conglomerates are characteristic. Provenance is the same as that for S_1, being the Precambrian Shield, but the depositional environment is interpreted as fluviatile in contradistinction to coastal for S_1.

The type Success Formation is limited by pre-Cantuar uplift and erosion to the area east of Range 7 west of the Third Meridian (Longitude 106°) and south of Latitude 51° (Figure 1) or, in effect, to the crest of the Swift Current structural platform. By reference to the micropaleontological correlation of the Vanguard units by Brooke and Braun (op. cit.) and by geophysical log correlation from the Tidewater Frontier Crown No. 1 well (Lsd. 13, Sec. 21, Twp. 3, Rge. 20W3) to the Fergus basin of central Montana, the S_1 member was equated with the Kimmeridgian Morrison Formation and the S_2 member with the Aptian Lakota sandstone (Christopher, 1974, Figure 16). Similarly Hayes (1983), by correlation from the same well where the S_1 member was dated palynologically as Upper Jurassic, traced it to the Swift sandstone of the Sweetgrass arch of southern Alberta.

1. Success Formation of Southeastern Saskatchewan

Strata equivalent to the Success Formation are also present in southeastern Saskatchewan. They lie between the Third Meridian (Longitude 106°) and the Manitoba border and generally south of Township 9, and are separated from the western body by a 96 km wide Cantuar corridor. The eastern body, though areally depicted in Christopher (1980, 1984a), is neither described in the literature nor recognized in Saskatchewan as a unit separate from the overlying Cantuar Formation. A complete core of this formation from the CDR Flat Lake Water Source well (Lsd. C3, Sec. 3, Twp. 1, Rge. 16 west of the Second Meridian (Figure 1)) and stored at the Subsurface Geological Laboratory, is here described and presented as a standard reference

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(1) Consultant, Regina, Saskatchewan
(2) Oldest to youngest

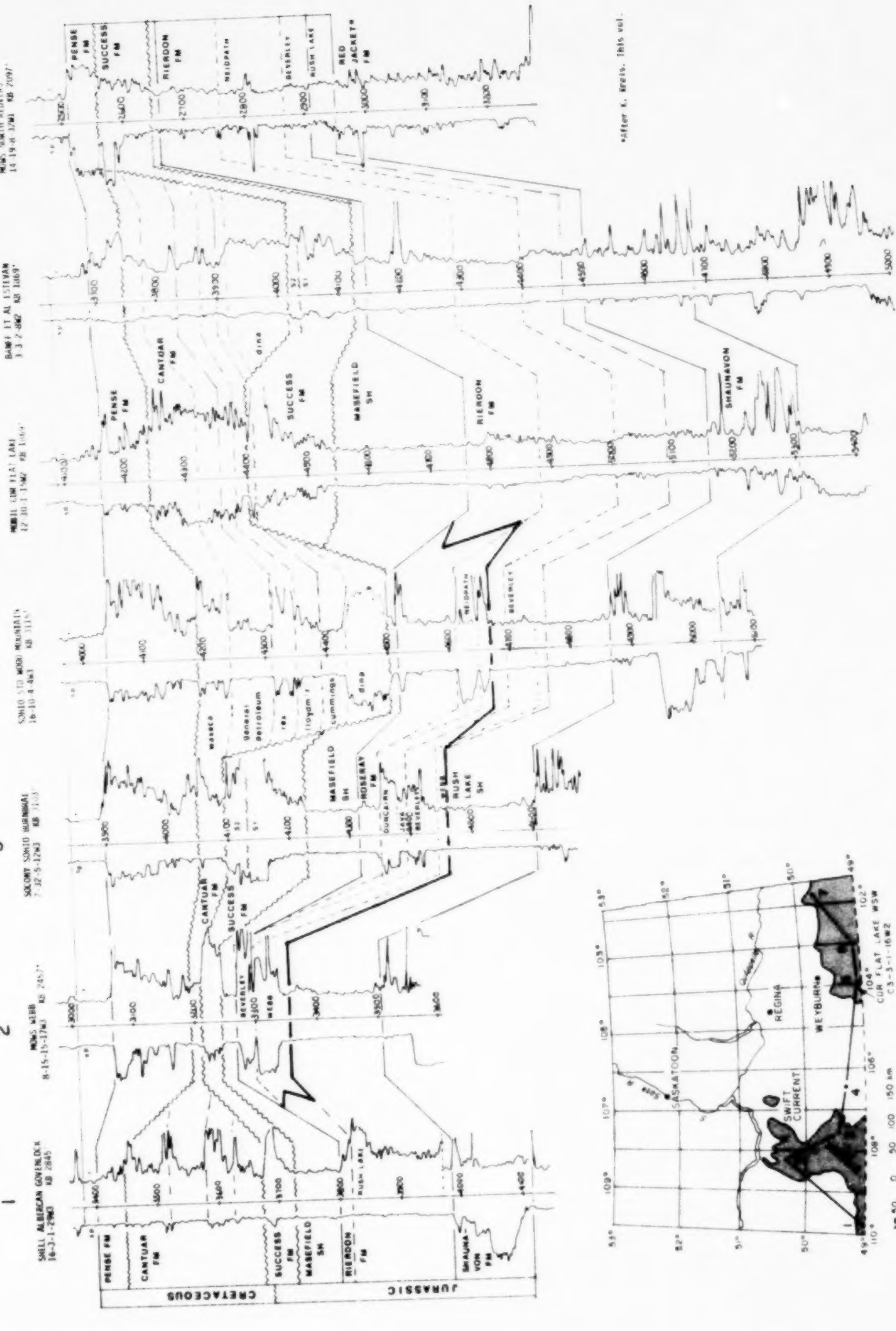
1
SHELL ALBERCAN GOVENLOCK 16-3-1-29W3 KB 2845
2
MOBS WEBB 8-15-15-17W3 KB 2457'
3
SOCONY SOHIO BURNHAM 7-32-5-12W3 KB 2103
4
SOHIO STD WOOD MOUNTAIN 16-10-4-4W3 KB 3115'
5
MOBIL COR FLAT LAKE 12-30-1-15W2 KB 3169'
6
BAMF ET AL ESTEVAN 3-3-2-8W2 KB 1869'
7
MOBS NORTH REDVERS 14-19-8-32W1 KB 2097'
CRETACEOUS
JURASSIC
PENSE FM
CANTUAR FM
SUCCESS FM
MASEFIELD SH
RIERDON FM
SHAUNAVON FM
RUSH LAKE
BEVERLEY
WEBB
ROSERAY FM
DUNCAIRN
LAKE BEVERLEY
RUSH LAKE SH
WEBB
Waseca
General Petroleum
Rex
Lloydm.
Cummings
Dina
NEIDPATH
BEVERLEY
RED JACKET* FM
*After K. Kreis. This vol.
SASKATOON
SWIFT CURRENT
REGINA
WEYBURN
COR FLAT LAKE WSW C3-3-1-16W2
km 50 0 50 100 150 km
mi 40 0 40 80 mi
53°
52°
51°
50°
49°
110°
109°
108°
107°
106°
105°
104°
103°
102°

Figure 1 – West-east geologic cross-section illustrating Jurassic Formation relationships across southern Saskatchewan.

section for the region. The geophysical log is portrayed in Figure 2.

In summary, the section of the Success Formation is 37 m thick and presents an upward transition from basal dark grey shales grading by lamination and interbedding through current-bedded, flasered, bioturbated and podded shale-draped green glauconitic siltstones, to very fine grained cream-coloured kaolin-indurated quartzose sandstones. A thin S_2 member, composed of very fine to medium-grained cream-coloured kaolin-indurated poorly sorted quartzose sandstone with abundant brown sphaerosiderites and siliceous kaolinitic conglomerates, caps the S_1 member. However, the contact, though irregular, reveals soft sediment deformation on the S_1 member and thereby indicates only a brief hiatus. Palynomorphs (dynocysts) collected from the S_1 member were dated as Late Middle to Late Oxfordian (courtesy of T. Poulton, Institute of Sedimentary and Petroleum Geology). The S_2 member is not dated.

2. Core Description for CDR Flat Lake WSW (Lsd. 3, Sec. 3, Twp. 1, Rge. 16W2)

Depths are in feet with the metric equivalent in parentheses.

K.B. 2261 ft (689.6 m)

a) Cantuar Formation

4385.0-4389.0 (1336.5-1337.8)	Mudstone: olive green, subordinate argillaceous siltstone, abundant carbonized plant fragments; bedding disrupted by plastic deformation; below 4388 (1337.5) rock becomes a claystone. Sharp irregular contact.
4389.0-4396.0 (1337.8-1339.9)	Siltstone: dark grey, massive, but penetrated by dark grey clay-filled anastomosed root burrow-fills; interbedded with beds of argillaceous, poorly sorted, fine to medium quartzose sandstones, at 4394.0-4395.0 (1339.3-1339.6) and 4395.5-4396.0 (1339.7-1339.9). Contacts are intergradational and sandstones include granules and blebs of coarse-grained pyrite.
4396.0-4397.0 (1339.9-1340.2)	Conglomerate: pebbles of quartzose, fine grained, silica-cemented sandstone; light grey; hard, dense like a quartzite. Basal contact not seen.

b) Success Formation

S_2 Member

4397.0-4399.5 (1340.2-1341.0)	Sandstone: quartzose, very fine to medium, poorly sorted, larger grains are rounded; well indurated in earthy kaolinitic and quartzose silt; cream coloured, large, mudstone-infilled, oblique fracture-joints; also cream-coloured siliceous kaolinitic irregular pebbles; abundant coarse sphaerosiderites. Irregular contact indented on an apparent soft sediment.

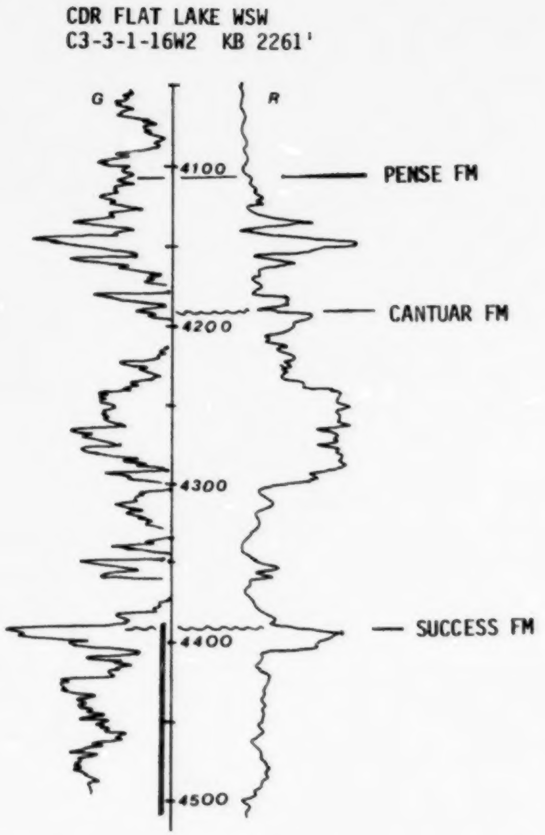

Figure 2 - Geophysical log for well CDR Flat Lake WSW 3-3-1-16W2, southeastern Saskatchewan.

S_1 Member

4399.5-4401.5 (1341.0-1341.6)	Siltstone: quartzose, well indurated in cream-coloured siliceous kaolinite; minor, increasing to subordinate, light grey-green argillaceous partings; bedding is crenulated, with traces of current lamination, but also deformational stretching.
4401.5-4405.5 (1341.6-1342.8)	Mudstone: glauconitic, dark grey-green variegated with yellow and purplish reds, interbedded with subordinate flasers, lenticles and thin beds of cross-bedded cream-coloured quartzose, kaolinitic, indurated siltstone; abundant red-brown sphaerosiderites and muscovite throughout. Sharp, irregular contact.

4405.5-4419.0 (1342.8-1346.9)	Siltstone: quartzose, grey-white grading to medium grey-green with increasing glauconitic content; kaolinitic argillaceous matrix; current-bedded with subordinate grey-black shale drapes and thin interbeds; crossbedding marked by small-scale, current, cut-and-fill lenses, ranging in thickness from 0.6 to 7.5 cm, bifurcating and terminating in black shale; pods and flame structures in evidence, as well as tool markings and burrow casts. Shale constitutes about 20 percent of thickness.
4419.0-4420.0 (1346.9-1347.2)	Shale: dark grey laminated with green; clayey.
4420.0-4434.5 (1347.2-1351.6)	Sandstone: quartzose, very fine, well sorted, glauconitic, medium grey-green, silty to argillaceous matrix, moderately indurated; generally current-bedded with minor green and black shaly partings; some shale laminae feature burrow casts and trail markings; low-angle, cut-and-fill bedding is a minor feature at 4432.0 (1350.9).
4434.5-4444.0 (1351.6-1354.5)	Laminated, very fine, green, glauconitic quartzose sand, and black shale draping cross-bedded, scour-and-fill, lensoid sandstone bodies; interbedded with trough cross-bedded sandstones 5 to 8 cm thick; abundant bedding-aligned sand-fill burrows and trails, as well as rolls and, on some, concentrated small pelecypod molds.
4444.0-4452.0 (1354.5-1357.0)	Siltstone: quartzose, coarse, glauconitic, medium grey-green; thin 2 to 5 cm trough-truncation sets and ripple drift-bedding; calcareous argillaceous matrix; thinly interbedded with dark grey bioturbated and sand-podded mudstones and black shale.
4452.0-4457.5 (1357.0-1358.6)	Siltstone: quartzose, coarse, glauconitic, medium grey-green argillaceous; thin cut-and-fill bedding, podded, bioturbated and compaction attenuated. Thinly interbedded with dark grey bioturbated shale, silty mudstone and black shale drapes on thicker sandstone lenticles.
4457.5-4461.0 (1358.6-1359.7)	Sandstone: quartzose, very fine; argillaceous matrix, glauconitic, medium grey-green; well indurated; cross-bedding variable, small-scale but mostly current scour-and-fill; some black shale drapes and sand-filled pods. Calcite-cemented at 4459.0-4460.0 (1359.1-1359.4).
4461.0-4466.0 (1359.7-1361.2)	Shale: olive-green, glauconitic; laminated with mudstone, light green-grey; minor boudinage and compactional deformation.
4466.0-4468.0 (1361.2-1361.8)	Laminated green, glauconitic argillaceous siltstone and black shale. Minor current bedding, flasers and shale drapes.
4468.0-4472.0 (1361.8-1363.1)	Sandstone: quartzose, very fine, glauconitic, argillaceous, medium grey-green; low-angle cross-bedded and flat-bedded; minor black shale partings.
4472.0-4473.5 (1363.1-1363.5)	Siltstone: quartzose, glauconitic, argillaceous; laminated with black shale; some current-bedded flasers.
4473.5-4480.0 (1363.5-1365.5)	Siltstone: quartzose, glauconitic, argillaceous; calcareous and calcite-cemented at 4473.5-4475.5 (1363.5-1364.1); cut-and-fill thin cross-bedding; minor black shale wavy drape laminae; 4 cm thick graded mudstone layer at 4475 (1364.0).
4480.0-4495.0 (1365.5-1370.1)	Laminated green, glauconitic, argillaceous siltstone and black shale; abundant bioturbation bedding casts (pods) and compactional attenuation of black shale on siltstone flasers and lenticles.
4495.0-4496.5 (1370.1-1370.5)	Sandstone: quartzose, very fine argillaceous matrix, glauconitic, medium grey-green, massive, well indurated; faint larger scale truncational cross-sets. Thin gradational contact with
4496.5-4499.0 (1370.5-1371.3)	Shale: grey-black, 6 inches (15 cm) thick, and mudstone, dark grey; bedded and interbedded green silty mudstone and dark grey shale. Strongly glauconitic at base.
4499.0-4501.5 (1371.3-1372.1)	Shale: dark grey, noncalcareous.
4501.5-4506.5 (1372.1-1373.6)	Mudstone, silty and siltstone: quartzose, argillaceous, medium green-grey, well indurated; laminated and thinly interbedded with dark grey shale; faintly current-bedded with scoured contacts and shale drapes; vertical escape burrow forms at 4503.5 (1372.7).
4506.5-4508.0 (1373.6-1374.0)	Shale: dark grey; minor thin beds (5 to 10 cm) of mudstone in upper portion; noncalcareous. End of core.

3. Swift-Rierdon Nomenclatural Differences

The standard formation names for the marine Upper Jurassic of North Dakota, Montana and southern Alberta are the Rierdon and Swift. However, the terms as used in the west versus those used in the east only partially encompass age-equivalent strata. This stratigraphic incongruency is attributable to mapping units in the Rierdon that actually represent calcareous fondobeds and which in Saskatchewan are partially bottom-sets of Roseray clinobeds.

The nearest approximations to time-stratigraphic horizons in the Vanguard succession are the Rierdon – Shaunavon and Roseray – Masefield contacts. Both contacts represent end-phases of basin filling. Whereas the other beds of the Roseray interval are generally isochronous, stratigraphically they slope as an eastward progradational offlapping sequence from west to southeast across the sandstone facies into the shale facies of the underlying Lower Vanguard or Rush Lake Shale. The degree of slope decreases upward, thereby reflecting the filling up of an initial starved basin (Christopher, 1984a). On the other hand, the Masefield-Success and the Success-Cantuar contacts are erosional and unconformable. These relationships are illustrated in the cross-section of Figure 1, which extends across Saskatchewan from Alberta to Manitoba and is highlighted by representative well-sections.

Because of the scarcity of core from the Success Formation of southeastern Saskatchewan, the Late Oxfordian S_1 member cannot be effectively mapped separately from the S_2 member. The latter, by virtue of the intervening disconformity, may be Kimmeridgian or younger. Thus the Jurassic-Cretaceous boundary may, for practical purposes, be placed at the Success-Cantuar or Success-Pense contact as the case may be (i.e., 30 to 45 m above the currently selected pick on the Masefield Shale). In western Montana and southeastern Alberta, the Success S_1 Member and Masefield Formations constitute the Swift Formation. The two units are traceable across Saskatchewan in stratigraphic contact despite the significant unconformity between them.

For its part, the Rierdon in the west comprises about 60 m of shale, of which the lower 54 m are pre-Roseray and the upper 6 m are Roseray-equivalent. However, the Rierdon thickens to more than 120 m by the acquisition of Roseray sigmoidal wedges eastward toward the basin center. Here the pre-Roseray Bathonian wedge of the west attenuates to a basal unit, 9 to 10 m thick, under the mass of Callovian – Oxfordian Roseray-equivalent shales.

It is also apparent that the top of the Rierdon shale of eastern Saskatchewan, where defined by the "Rierdon shoulder", is on the Beverley fondobed of the Roseray unit. Mapping on this "shoulder", as is the current practice, creates a grave distortion in any reconstruction of the Rierdon depositional basin. For example, at the well MOWS North Redvers (Lsd. 14, Sec. 19, Twp. 8, Rge. 32 west of the First Meridian) the "Rierdon shoulder" is located at 2868 ft (871.9 m) below K.B., which is 42 ft (12.7 m) above the pre-Roseray Rierdon top and 208 ft (63.4 m) below the Roseray – Rierdon top.

Another relationship of major significance is the contact between the Masefield Shale and the Success S_1 member (i.e., the contact between the Swift Shale and the Swift Sandstone). This is a significant unconformity beneath which the shale body may, in places, be entirely absent. Thus, recognizing the Success S_1 member and the Masefield Shale as separate entities provides for a more precise stratigraphic delineation than combining them in a generalized Swift Formation.

Whereas the Success S_1 and S_2 relationship is disconformable where seen in core, both units exhibit a quartz-kaolin provenance. Differentiation of S_1 by a pyrite-glauconite accessory suite versus the siderite-carbonaceous suite of S_2, and by the laminated to fine-bedded and bioturbated texture of S_1 versus the poorly sorted coarser grains and trough cross-bedding of S_2 reflects the S_1 marine origin versus continental deposition of S_2. One could say that the S_2 member is a later regressive facies of the S_1. This terminal marine to continental transition is not unlike that ascribed to the Swift (Oxfordian) – Morrison (Kimmeridgian) transition in the southern part of the Williston Basin of Montana and North Dakota (Imlay, 1980).

Current practice incorporates Success strata as a pre-Cantuar basal Mannville unit. The lower age limit of the Cantuar is unknown, but Aptian is a good estimate. The upper limit of the Success in southeastern Saskatchewan is more than likely Kimmeridgian but is probably younger in the homologous basins of central Saskatchewan where it is considerably thicker (Christopher, 1984b, 1987). Recognition of the Success as a stratigraphic body separate from the Cantuar Formation makes possible a more precise mapping of the pre-Cantuar erosion surface. This has been vital to understanding petroleum reservoir control in southwestern Saskatchewan. It would also add precision to knowledge of the geological environment in eastern Saskatchewan.

4. References

Brooke, M., and Braun, W.K. (1972): Biostratigraphy and microfaunas of the Jurassic System of Saskatchewan; Sask. Dep. Miner. Resour., Rep. 161, 83p.

Christopher, J.E. (1974): The Upper Jurassic Vanguard and Lower Cretaceous Mannville Group of southwestern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 151, 349p.

_________ (1980): The Lower Cretaceous Mannville Group of Saskatchewan – a tectonic overview; *in* Beck, L.S., Christopher, J.E. and Kent, D.M. (eds.), Lloydminster and Beyond: Geology of Mannville Hydrocarbon Reservoirs; Sask. Geol. Soc., Spec. Publ. 5, p3-32.

_________ (1984a): Depositional patterns and oilfield trends in the Lower Mesozoic of the northern Williston Basin, Canada; *in* Oil and Gas in Saskatchewan; Sask. Geol. Soc., Spec. Publ. 7, p83-102.

_________ (1984b): The Lower Cretaceous Mannville Group, northern Williston Basin region, Canada; *in* The Mesozoic of Middle North America; Can. Soc. Petrol. Geol., Mem. 9, p109-126.

_________ (1987): Note on the Jura-Cretaceous section in central southeastern Saskatchewan; *in* Summary of Investigations 1987; Sask. Geol. Surv., p194-198.

Cobban, W.A. (1945): Marine Jurassic formations of Sweetgrass Arch, Montana; Am. Assoc. Petrol. Geol. Bull., v29, p1262-1303.

Francis, D.R. (1956): Jurassic stratigraphy of the Williston Basin area;; Sask. Dep. Miner. Resour., Rep. 18, 69p.

_________ (1957): Jurassic stratigraphy of the Williston Basin area;; Am. Assoc. Petrol. Geol., v41, p367-398.

Hayes, B.J.R. (1983): Stratigraphy and petroleum potential of the Swift Formation (Upper Jurassic), southern Alberta and north-central Montana; Bull. Can. Petrol. Geol., v31, p37-52.

Imlay, R.W. (1945): Occurrence of Middle Jurassic rocks, Western Interior of the United States: Am. Assoc. Petrol. Geol. Bull., v29, p1019-1027.

_________ (1947): Marine Jurassic of Black Hills area, South Dakota and Wyoming: Am. Assoc. Petrol. Geol. Bull., v31, p227-273.

_________ (1980): Jurassic paleobiography of the conterminous United States in its continental setting; U. S. Geol. Surv., Prof. Pap. 1002, 132p.

Imlay, R.W., Gardner, L.S., Rogers, C.P. and Hadley, D. (1948): Marine Jurassic formations of Montana; U. S. Geol. Surv., Oil and Gas Invest., Prelim. Chart 32.

Maycock, I.D. (1967): Mannville Group and associated Lower Cretaceous rocks in southwestern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 96, 108p.

Milner, R.L. and Blakslee, G.W. (1958): Notes on the Jurassic of southwestern Saskatchewan; *in* Jurassic and Carboniferous of Western Canada; John Andrew Allan Mem. Vol., Am. Assoc. Petrol. Geol., p65-84.

Milner, R.L. and Thomas G.E. (1954): Jurassic System in Saskatchewan; *in* Western Canada Sedimentary Basin; Am. Assoc. Petrol. Geol., p250-267.

Nolte, C.J. (1967): The Middle Jurassic sandstone: a prolific Jurassic objective in southwestern Saskatchewan, Canada; The Mountain Geologist, v4, p41-51.

Peterson, J.A. (1957): Marine Jurassic of northern Rocky Mountains and Williston Basin; Am. Assoc. Petrol. Geol. Bull., v41, p399-440.

Poulton, T.P. (1984): The Jurassic of the Canadian Western Interior from 49°N Latitude to Beaufort Sea; *in* Stott, D.F. and Glass, D.J. (eds.), The Mesozoic of Middle North America; Can. Soc. Petrol. Geol., Mem. 9.

Price, L.L. (196[illegible]): Lower Cretaceous rocks of Saskatchewan; Geol. Surv. Can., Pap. 62-69, p55.

Springer, G.D., McDonald, W.D. and Crockford, M.B.B. (1964): Jurassic; *in* Geological History of Western Canada; Alberta Soc. Petrol. Geol., Calgary, p137-155.

Lithology and Stratigraphy of Lower Paleozoic Strata: New Information from Cores in the Cumberland Lake Area, East-Central Saskatchewan

F.M. Haidl

Haidl, F.M. (1988): Lithology and stratigraphy of lower Paleozoic strata: new information from cores in the Cumberland Lake area, east-central Saskatchewan; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

Lower Paleozoic strata outcrop at a number of localities in the Cumberland Lake area of east-central Saskatchewan (Kupsch, 1952). Correlation of these outcrops with strata in the subsurface of southern Saskatchewan is hampered by limited exposures in the field and by a paucity of subsurface information north of Township 50. In the summer of 1988, four new cores and supplementary data from recent drilling projects were kindly made available to Saskatchewan Energy and Mines by Cominco Ltd. This new information should facilitate stratigraphic correlation in the area.

The locations of the four Cominco cores are shown in Figure 1. Cores SR1 and SR3 were taken by Cominco in the winter of 1986 as part of the Squaw Rapids drilling project (in the Cumberland Delta area, north of Squaw Rapids). Both cores are continuous from near the top of the Lower Interlake to a few metres below the Paleozoic/Precambrian contact (Figure 2). Cores from the Berland project (Ber3 and Ber4) were taken from holes drilled through the ice on Cumberland Lake in March 1988. A cursory examination of these cores suggests that they encompass strata from uppermost Precambrian to at least as high as the Stonewall Formation, and possibly even part of the lowermost Lower Interlake. All four cores have a diameter of 4.5 cm and were taken from directionally drilled holes; all depth and thickness values given here have been corrected to true vertical depth.

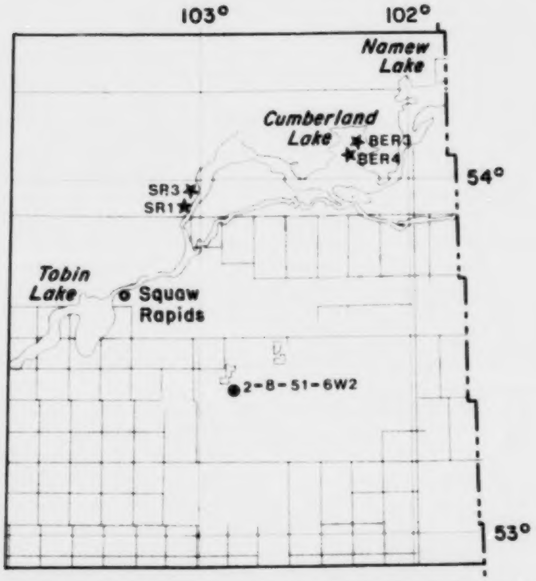

Figure 1 - Map showing the location of cores SR1, SR3, Ber3 and Ber4, as well as that of California Standard Pasquia Hills 2-8-51-6W2, the reference well used in correlation of cores to subsurface stratigraphic units (Figure 2). Also shown is the location of the Namew Island outcrop on Namew Lake.

Data from these cores will be incorporated in an ongoing regional study of Silurian strata in Saskatchewan, initiated by the author in 1986 (Haidl, 1987). Probable stratigraphic correlations and a brief description of lithologies in SR1 and SR3 are presented here.

1. Stratigraphic Correlation

The correlation of stratigraphic units in SR1 and SR3 with those in the subsurface of southern Saskatchewan is illustrated in Figure 2 and is based on the presence of marker beds observed in core and defined on geophysical well logs in Ordovician and Silurian strata (Kendall, 1976; Haidl, 1987), as well as on lithologic similarities to Ordovician and Silurian strata described by other workers (e.g., Paterson, 1971; Kendall, 1976; Jamieson, 1979).

The quartz sandstone of the Winnipeg Formation (Middle Ordovician) is the lowermost Paleozoic unit in the Cumberland Lake area. Weathered Precambrian rocks are unconformably overlain by a silty sandstone at the base of the Winnipeg Formation.

The clastics of the Winnipeg Formation are disconformably overlain by the burrow-mottled dolomites of the Yeoman Formation (Upper Ordovician). This contact is sharp in SR1 where a basal Yeoman dolomite bed, with only scattered quartz sand grains, directly overlies the argillaceous burrowed siltstone in the upper Winnipeg Formation. In SR3 there is a much more gradational change from clastics to carbonates and, therefore, the contact is more difficult to define. Using the criteria of Paterson (1971), the Yeoman/Winnipeg contact is placed at the point where grain-supported sandstones change to matrix-supported dolomites.

The Herald/Yeoman contact is not well defined in SR1 and SR3. Kendall (1976, p.15) stated that the Herald/Yeoman contact "is transitional with only slight evidence for any break in deposition" and is "one of the most difficult to locate in cores". In the Cumberland Lake area, the top of the Yeoman Formation is placed at the top of

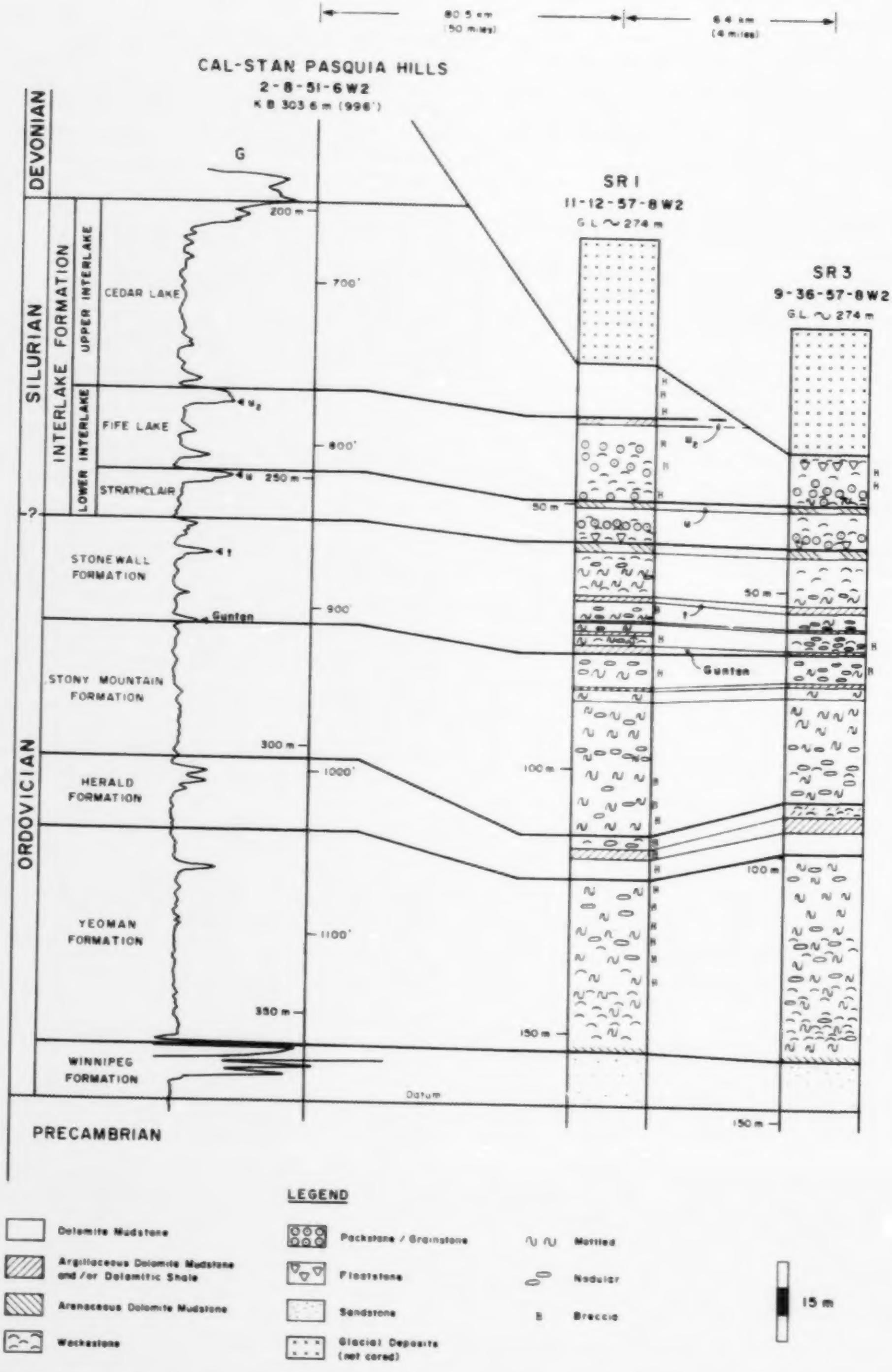
80.5 km
(50 miles)
6.4 km
(4 miles)
CAL-STAN PASQUIA HILLS
2-8-51-6W2
K.B. 303.6 m (996')
G
SR1
11-12-57-8W2
G.L. ~ 274 m
SR3
9-36-57-8W2
G.L. ~ 274 m
DEVONIAN
SILURIAN
ORDOVICIAN
PRECAMBRIAN
INTERLAKE FORMATION
UPPER INTERLAKE
LOWER INTERLAKE
CEDAR LAKE
FIFE LAKE
STRATHCLAIR
STONEWALL FORMATION
STONY MOUNTAIN FORMATION
HERALD FORMATION
YEOMAN FORMATION
WINNIPEG FORMATION
?
200 m
250 m
300 m
350 m
700'
800'
900'
1000'
1100'
50 m
100 m
150 m
Datum
u
t
Gunton
LEGEND
Dolomite Mudstone
Argillaceous Dolomite Mudstone and/or Dolomitic Shale
Arenaceous Dolomite Mudstone
Wackestone
Packstone / Grainstone
Floatstone
Sandstone
Glacial Deposits (not cored)
Mottled
Nodular
B Breccia
15 m

Figure 2 - Lithologies of cores SR1 and SR3 and the stratigraphic correlation of these cores to Cal-Stan Pasquia Hills 2-8-51-6W2, a reference well for which gamma ray (illustrated), neutron and electrical geophysical logs are available. The land locations (Western Canada Survey System) of SR1 and SR3 have been estimated from a location map provided by Cominco Ltd. Core depths have been corrected to true vertical depth.

the uppermost burrow-mottled dolomite unit which lies below the argillaceous strata of the Herald Formation.

The Stony Mountain/Herald contact is also poorly defined in this area. Neither the laminated microdolomite unit at the top of Herald nor the argillaceous marker bed which defines the base of the Stony Mountain Formation in Kendall's study area are present in cores SR1 and SR3. However, in SR3 a prominent truncation surface coincides with the base of a mottled nodular dolomite interval interpreted as Stony Mountain strata; the contact between the Stony Mountain and Herald is placed at this truncation surface. Brecciation of this zone in SR1 precludes the accurate delineation of the Stony Mountain/Herald contact; the pick is based on comparison with the lithologic sequence in SR3.

The remainder of the contacts between stratigraphic units are delineated by argillaceous and/or arenaceous marker beds. The top of the Stony Mountain Formation is picked at the base of a well-defined unit of argillaceous dolomite mudstones, correlative with the Gunton marker bed in southern Saskatchewan. The contact between the Stonewall Formation and the Strathclair subunit of the Interlake Formation is marked by the top of an interval of interbedded quartz sandstone and dolomite mudstones (Figure 2). The top of a marker bed ("u" marker, Figure 2) of similar lithology delineates the Fife Lake/Strathclair contact in the Lower Interlake unit. The top of the Fife Lake subunit is defined by the top of the "u_2" marker bed (Figure 2). In SR1, this contact is tentatively picked at the top of an interval of argillaceous dolomites with thin interbeds of sandstone. However, as this portion of the core is badly weathered, the validity of this pick is in question. In SR3, the erosion surface below the glacial drift truncates the Fife Lake subunit several metres below its projected top (Figure 2).

The intense weathering of the upper 10.1 m of the SR1 core precludes correlation of lithologies in this locality with those in cores in southern Saskatchewan, where the Guernsey subunit is the uppermost unit of the Lower Interlake (Haidl, 1987). Correlation of geophysical logs from the Calc-Stan Pasquia Hills well (2-8-51-6W2) with those from more southerly wells suggests, however, that the Guernsey subunit is absent in the northern portion of the province (Figure 2). Therefore, the upper 10.1 m of SR1 probably correlate with the Cedar Lake subunit of the Upper Interlake (Figure 2).

Thickness values for the Yeoman, Herald, Stony Mountain and Stonewall Formations, as defined in Figure 2, are in good agreement with those extrapolated from data in Kendall (1976). The combined Yeoman and Herald Formations appear to correlate with the Red River Formation as described in core and outcrop in Manitoba (McCabe, 1984, 1985, 1987).

2. Lithology

Lithologies within the Lower Paleozoic sequence in SR1 and SR3 are illustrated in Figure 2 and are briefly described below. Secondary breccias, abundant in SR1 and sparsely scattered in SR3, are discussed separately following the description of other lithologies in the stratigraphic sequence. The sequence is dominated by dolostones, all of which appear to be secondary. Nevertheless, original textures prior to dolomitization can be recognized in most cases and these allow the use of Dunham's classification of carbonate textures (Dunham, 1962), as modified by Embry and Klovan (1971). The carbonates are all dolomite, so its repetitive use as a lithologic adjective with the textural terms has been eliminated, except for the substitution of "dolomite" for "lime" in mudstone units.

a) Winnipeg Formation

The Winnipeg Formation is a sandstone unit composed predominantly of subangular to well-rounded quartz grains ranging in size from silt to coarse-grained sand. Sorting ranges from moderately well sorted in fine to medium sands, to poor to fair in intervals with a higher silt content (commonly burrowed). The uppermost portion (< 1 m) of the Winnipeg Formation consists of argillaceous burrowed siltstone with abundant sand intercalations.

Pyrite is fairly abundant throughout the Winnipeg Formation in SR1 and SR3. The most interesting occurrence is as bands of concentrically laminated pyrite spherules ("ooids") near the Precambrian contact in the SR3 core. Similar grains have been reported in other Winnipeg cores (Paterson, 1971). The mechanism responsible for the formation of these spherules is not known. Binda et al. (1985) speculated that sulphide ooids in a Proterozoic arenite had an authigenic chemical origin and formed during early diagenesis. The spherules in the Winnipeg Formation may reflect a similar genesis.

b) Yeoman Formation

The thin (<0.35 m) basal unit of the Yeoman Formation is a sandy dolomite. The remainder consists of burrowed, mottled, commonly nodular, skeletal dolomite mudstones and wackestones (Plates 1A and B). The skeletal material is finely comminuted and recrystallized; crinoid ossicles are the only recognizable allochems. Porosity resulting from the dissolution of fossil fragments is best developed in a 5 m interval near the base of this formation in SR3.

The burrowed, mottled nature of the Yeoman Formation observed in these cores is characteristic of this stratigraphic unit throughout the Williston Basin. Complex variations in the appearance of this relatively homogeneous lithology can be attributed to changes in 1) color, 2) shape, size and frequency of the mottles, and 3) the character of the burrows (Kendall, 1976). The depositional and diagenetic events responsible for these variations are discussed at length in Kendall (1976, 1977, 1985). Possible diagenetic pathways and related changes in appearance are summarized in Figure 3.

c) Herald Formation

The basal unit of the Herald Formation consists of cryptocrystalline to finely microcrystalline dolomite mudstones. This unit is overlain by a middle unit

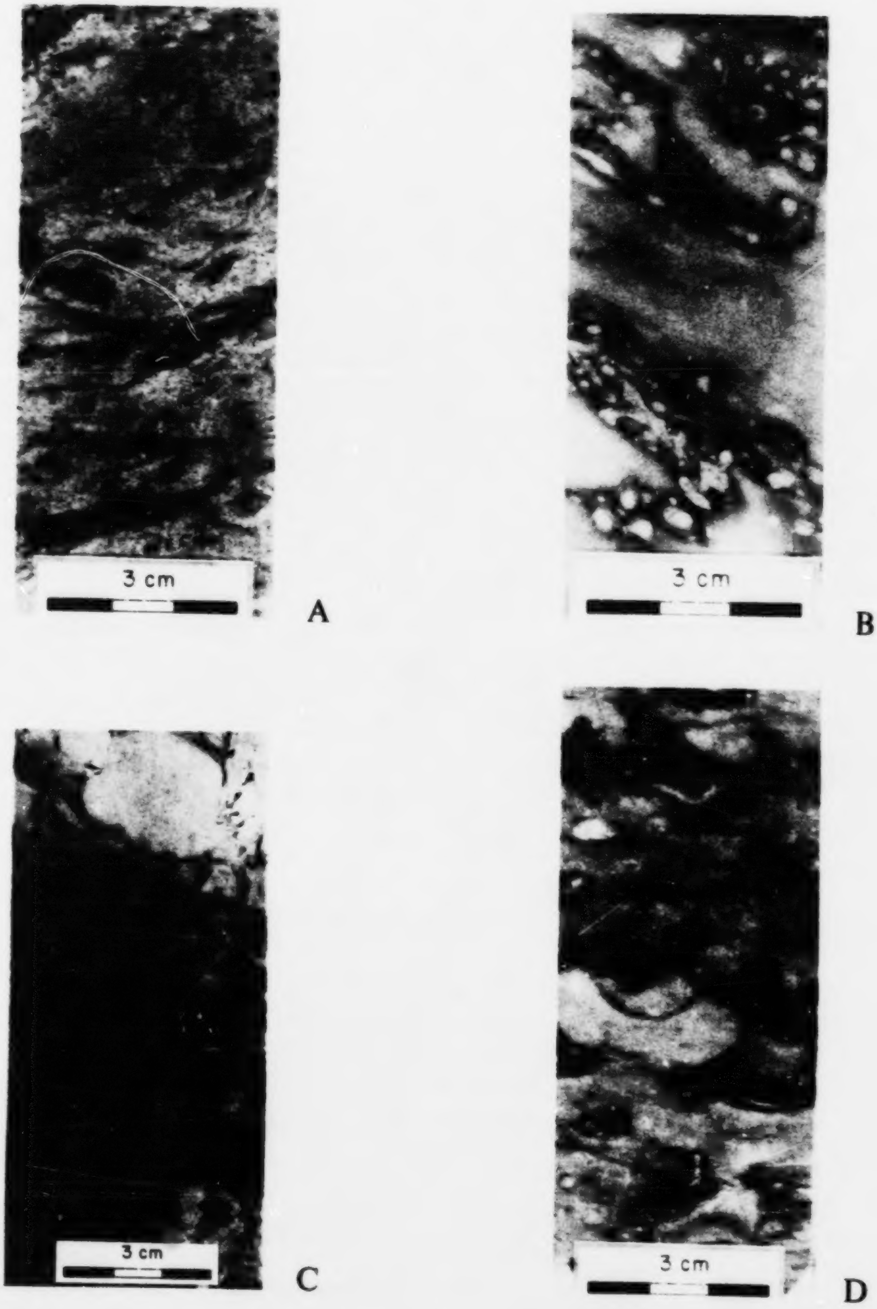

Plate 1 – A) Pyritic nodular skeletal wackestone with abundant solution stringers, Yeoman Formation, SR3, 134.7 m; note that cores SR1 and SR3 were taken from holes drilled at an angle of 65 to 68° to horizontal; all depths quoted have been corrected to true vertical depth. B) Dolomite mudstone with prominent burrow systems within large well-defined mottles, Yeoman Formation, SR3,104.6 m. C) Sharp contact (arrows) between a mottled dolomite mudstone and an overlying nodular mudstone is interpreted as the contact between the Stony Mountain and Herald Formations, SR3, 89.5 m; note the highly irregular contact between distinctly mottled dolomite and unmottled burrowed dolomite near the top of the Herald Formation. D) Hematite-stained, mottled skeletal wackestone with small burrows within the mottles, Stony Mountain Formation, SR3, 84.1 m; fossils include a small rugose coral (upper left) and a cast of a large gastropod(?) at left centre.

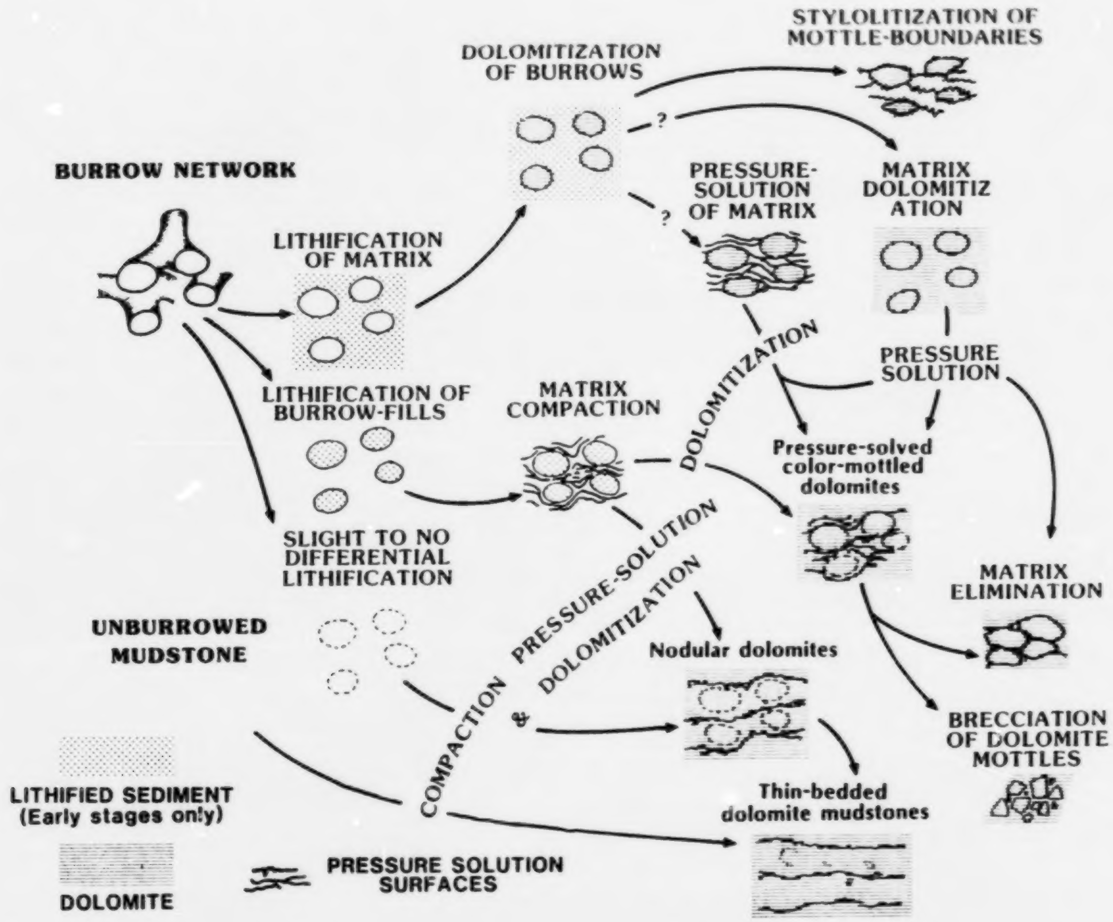
STYLOLITIZATION OF MOTTLE-BOUNDARIES
DOLOMITIZATION OF BURROWS
BURROW NETWORK
?
?
PRESSURE-SOLUTION OF MATRIX
MATRIX DOLOMITIZATION
LITHIFICATION OF MATRIX
DOLOMITIZATION
PRESSURE SOLUTION
LITHIFICATION OF BURROW-FILLS
MATRIX COMPACTION
Pressure-solved color-mottled dolomites
SLIGHT TO NO DIFFERENTIAL LITHIFICATION
PRESSURE-SOLUTION
MATRIX ELIMINATION
DOLOMITIZATION
UNBURROWED MUDSTONE
Nodular dolomites
COMPACTION
&
BRECCIATION OF DOLOMITE MOTTLES
LITHIFIED SEDIMENT (Early stages only)
Thin-bedded dolomite mudstones
DOLOMITE
PRESSURE SOLUTION SURFACES

Figure 3 – Modification of Yeoman carbonates by diagenetic processes (from Kendall, 1985). The entire Lower Paleozoic carbonate sequence in SR1 and SR3 has been subjected to similar diagenetic processes.

characterized by laminated to bedded, argillaceous to highly argillaceous dolomites, which display several sharp contacts and are locally overlain by thin (<0.5 cm) laminae of small dolomite clasts. Molds of skeletal halite crystals are present near the top of the middle unit. Abundant microfractures, infilled with pyrite, are present in these lower two units of the Herald.

The upper unit of the Herald Formation is composed of interbeds of dolomite wackestone, argillaceous dolomite mudstone and dolomitic shale. In SR3, the top of the Herald Formation is placed at a sharp contact between a mottled dolomite in the Herald Formation and a nodular dolomite in the Stony Mountain Formation (Plate 1C).

d) Stony Mountain Formation

The burrowed, mottled and commonly nodular dolomite mudstones and wackestones comprising the basal unit (<25 m) of the Stony Mountain Formation are very similar to those of the Yeoman Formation (Plates 1D and 2A; Figure 3). Fossil fragments, generally less abundant than in the Yeoman, include crinoid ossicles, gastropods and rugose corals. Mottling decreases upward into nodular to massive dolomite mudstones which are overlain by laminated and/or argillaceous dolomite mudstones and dolomitic shales. The upper unit of the Stony Mountain Formation consists of nodular and indistinctly mottled dolomite mudstones.

e) Stonewall Formation

The lower unit of the Stonewall Formation consists of repetitions of subunits comprising the following lithologic sequence: 1) basal argillaceous, laminated to bedded dolomite mudstones, 2) nodular, commonly burrowed dolomite wackestones and mudstones with minor brachiopods, favositid corals and other skeletal material, and 3) massive to bedded dolomite mudstones. Four

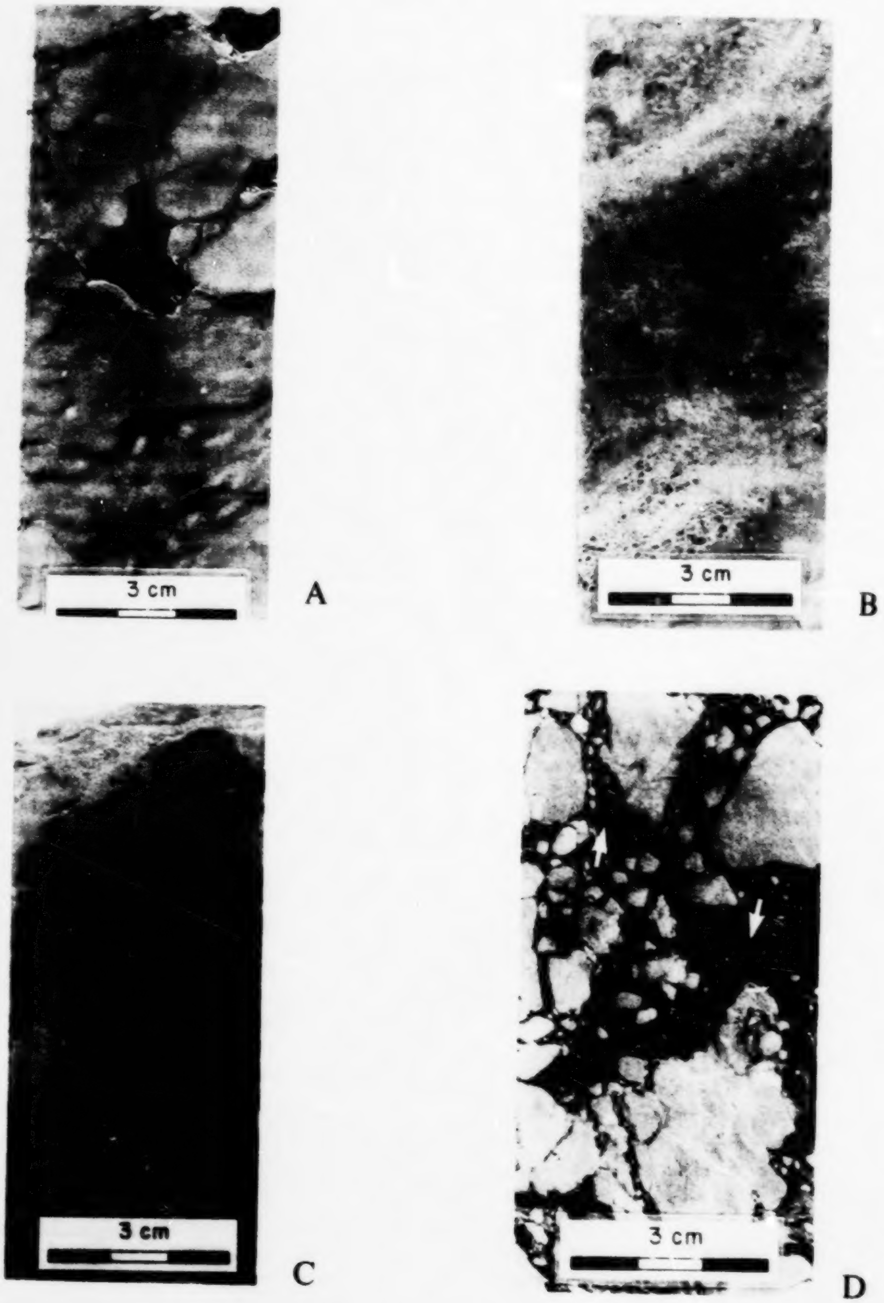

Plate 2 – A) Nodular dolomite mudstone with pressure solution stringers, Stony Mountain Formation, SR1, 96.0 m; solution cavities have developed along boundaries between a few nodules; cavities are commonly infilled with greenish-grey clay (c), although much of the clay has washed out during slabbing of the core. B) Coral floatstone, Strathclair subunit, Lower Interlake, SR1, 57.6 m; large favositid coral fragments in a skeletal wackestone matrix; other fossils in this unit include stromatoporoids, rugose corals and small brachiopods. C) Stromatoporoid floatstone in a mudstone matrix, Fife Lake subunit, Lower Interlake, SR3, 24.7 m; internal structures within stromatoporoids are extremely well preserved; fragments of rugose and favositid corals are also present in this unit. D) Matrix-supported breccia associated with fracturing, Yeoman Formation, SR1, 131.9 m; clasts composed of nodular dolomite mudstone display abundant microfractures; matrix consists of silt-sized dolomite and quartz sand grains, pyrite and kerogenous material (arrows).

subunits are present in SR1 and three in SR3. The basal mudstones (subunit 1) are especially well developed in the Gunton marker bed at the base of the Stonewall and in the "t" marker at the base of the thick (approximately 10.5 m) uppermost subunit (Figure 2).

The upper unit of the Stonewall Formation comprises thin interbeds of fine- to medium-grained quartz sandstone and dolomite mudstone. Contacts between the two lithologies are seldom sharp, with floating quartz sand grains commonly intercalated within the dolomites. In a few dolomite beds, irregular lenses of sandstone protrude into the dolomite, at times producing dolomite "clasts". The origin of this disruption in bedding is uncertain; it may be related to bioturbation and/or fluid escape. At the base of this upper unit in SR3, discrete lenses of quartz sandstone occur within a peloidal oolitic grainstone.

f) Interlake Formation

A thin exposure (2.1 m) of probable Interlake strata at Pine Island on Cumberland Lake (see below) represented the only accessible Lower Interlake strata north of Township 50 in Saskatchewan before the acquisition of the Cominco cores,. The cores provide valuable new information on this stratigraphic interval, as well as fossils and depositional textures which are significantly better preserved here than in most Interlake cores from southern Saskatchewan.

Lower Interlake, Strathclair Subunit:

The lowermost bed (<2 m) in the Strathclair is composed of fossiliferous floatstones and wackestones/packstones (Plate 2B). Fossils include favositid and rugose corals, hemispherical, bulbous and tabular stromatoporoids and abundant small disarticulated brachiopod(?) shells. Above this bed is a unit dominated by skeletal peloidal wackestones, packstones and grainstones with thin (<0.25 m) interbeds of dolomite mudstone. This in turn is overlain by a unit (<3.5 m) consisting of sublithographic dolomite mudstone, commonly laminated, particularly towards the top. The laminae are irregular, and coupled with the presence of interlaminar porosity, this suggests an algal origin.

The uppermost unit of the Strathclair is the "u" marker bed (Figure 2). In SR3, this bed consists of two thin (<0.25 m) intervals of interbedded quartz sandstone and dolomite mudstone separated by an argillaceous dolomite mudstone bed. The mudstone bed is characterized by numerous erosion surfaces overlain by small clasts of dolomite and scattered quartz grains. In SR1, no quartz sandstone is present near the top of the marker bed but the remainder of the sequence is similar to that in SR3.

Lower Interlake, Fife Lake Subunit:

The basal bed (0.35 m) of the Fife Lake subunit in core SR3 is a crossbedded peloidal grainstone with good porosity. The well-rounded and well-sorted carbonate grains have been completely recrystallized; more detailed petrographic studies may facilitate interpretation of their depositional history. In SR1, the lowermost Fife Lake bed consists of interbeds of skeletal, peloidal grainstone and dolomite mudstone. Above the basal bed in both cores is a fossiliferous wackestone unit (<3 m) which contains orthoconic cephalopod shells, brachiopods, crinoids and favositid corals. This lithology is also an important component of the overlying unit which, in both cores, consists of interbeds of skeletal wackestones, oolitic peloidal packstones/grainstones and dolomite mudstones. Laminated mudstones, which include intervals of intraclasts stacked almost vertically (Plate 2C) and zones of fenestral porosity, dominate the upper part of this interbedded unit.

Correlation between the two cores breaks down at this level because of intense weathering in SR1. In SR3, in which original textures are well preserved over the entire cored interval, the interbedded unit is overlain by a stromatoporoid floatstone which displays excellent preservation of internal structure within tabular, bulbous and hemispherical stromatoporoids. The uppermost interval is a skeletal packstone/wackestone which includes crinoid, coral and brachiopod fragments. The remainder of the Lower Paleozoic sequence at this location has been removed by erosion associated with the subglacial unconformity.

The upper 19 m of SR1 are so intensely weathered that it is difficult to ascertain original textures and lithologies above the middle of the interbedded unit. A sequence of argillaceous dolomites with interbeds of sandstone (33.9 to 35.1 m) is tentatively interpreted as the "u_2" marker bed that occurs at the top of the Fife Lake subunit (Figure 2). The sandstones are composed of very fine sand and silt quartz grains, fine to medium dolomite sand grains, and authigenic quartz (including numerous euhedral bipyramidal crystals). Although this interval is in the correct stratigraphic position to be the "u_2" marker bed, it is difficult to determine whether the sandstone beds are part of the original depositional sequence. Their proximity to the unconformity and the brecciated nature of the overlying beds suggest that the sandstones may represent cavity-fill material which has been transported from the unconformity surface.

Upper Interlake, Cedar Lake Subunit:

Based on geophysical well log correlations, the uppermost 10.1 m in SR1 correlate to the Cedar Lake subunit of the Upper Interlake (Figure 2). The lower 2.3 m are composed of intensely weathered dolomite mudstone(?). The remainder of the core consists of matrix-supported breccias composed of weathered angular to subrounded clasts in an argillaceous silt matrix.

g) Secondary Breccias

The SR1 core is characterized by extensive intervals of brecciation from approximately 11 m above the base of the Yeoman Formation to the top of the core. A few brecciated zones are also present in SR3. Clasts within the breccias are subrounded to angular and range in diameter from less than 2 mm to more than 4.5 cm (i.e., greater than the diameter of the core). Textures range from tightly packed clast-supported breccias with virtually no matrix to those with clasts floating in abundant matrix.

Thin beds or laminae of matrix-supported dolomite clasts (commonly above erosion surfaces) occur as minor constituents in dolomite mudstone units in stratigraphic intervals above the Yeoman Formation, and are interpreted as primary breccias (i.e., part of the original depositional sequence). However, the majority of the brecciated intervals are interpreted as secondary breccias related directly to one or more of 1) diagenetic processes, 2) natural fractures, and 3) coring-induced fractures. This interpretation is based on the following: a paucity of sharp contacts between breccias and adjacent beds except where bounded by well-defined fracture planes; an abundance of clasts with fresh broken surfaces; an abundance of brecciated intervals with very little to no matrix; common discordance of bedding in matrix-supported breccias to the bedding in adjacent beds.

The texture and distribution of the secondary breccias appear to be controlled primarily by the degree and nature of chemical compaction (Figure 3) and also the intensity of fracturing. Chemical compaction is controlled in part by the original lithology and previous diagenesis (Kendall, 1985). The much more extensive brecciation observed in SR1 compared to SR3 can be ascribed to an abundance of oblique and vertical natural fractures in SR1 and a paucity of such fractures in SR3.

Matrix-supported breccias are most extensive in the Yeoman Formation in SR1 and appear to have formed in solution cavities developed along fracture planes. The majority of clasts appear to have been derived *in situ* and are likely the product of 1) fracturing and 2) dissolution of intervening material from between mottles or nodules in the mottled dolomites which characterize the Yeoman Formation. The matrix is commonly composed of silt-sized dolomite grains, subrounded to rounded quartz grains and pyrite. Kerogenous material is common in the matrix of breccias from 131.7-137.7 m in SR3 (Plate 2D). The presence of the quartz grains and concentrations of kerogenous matter suggest transport of matrix material from external sources along fracture planes and possibly joints.

Solution cavities have also developed along fracture planes in the Stony Mountain Formation. One such unit in SR1, approximately 0.35 m thick, is filled with greenish-grey argillaceous siltstones with only a few intraclasts of dolomite near the highly irregular upper and lower contacts. If the irregular contacts with adjacent beds and the associated clasts had not been preserved in core, this bed could be interpreted as part of the depositional sequence rather than as a cavity fill. Similarly, thin beds of claystone, which are common as cavity fills in nodular dolomites (see below), may appear to be primary deposits when observed in outcrop or core.

Nodular dolomites, characterized by an almost total absence of original matrix material, are also commonly brecciated in SR1. Small solution cavities, typically infilled with greenish-grey, generally silty clay, commonly develop at the boundaries between the nodules (Plate 2A). These cavities, while producing some clasts, are rarely extensive enough to account for the abundance of clasts in these breccias. Rather, when subjected to stresses induced by coring, boundaries between the nodules appear to have acted as planes of weakness and the rock has fractured intc large irregular clasts with abundant fresh broken surfaces. Coring-induced stress is also likely to be responsible for breccias formed in rocks displaying 1) abundant natural irregular hairline fractures, 2) little evidence of chemical compaction, and 3) no evidence of matrix material.

3. Correlation of Cores with Outcrop

The author has not examined outcrops in the Cumberland Lake area; comments on possible correlations are based on lithologic descriptions in Kupsch (1952) and on geophysical log correlations of wells in Kupsch's study area with those in Kendall's study area (Kendall, 1976).

Many outcrops in the area are of limited vertical extent and are composed entirely of dolomites which are burrowed and mottled. This same lithology is seen in core to be typical of both the Yeoman Formation and the lower Stony Mountain Formation; thus it is difficult, if not impossible, to assign stratigraphic position of each outcrop on lithological grounds alone. *Receptaculites*, commonly recorded from the Red River Formation (e.g., Baillie, 1952), has not been reported however, from Stony Mountain strata and it seems most likely that the *Receptaculites*-bearing strata belong to the Yeoman Formation (previously the Yeoman Member of the Red River Formation).

One of the thickest sections of Lower Paleozoic strata exposed in this area (Section 10 in Kupsch, 1952) is found on Namew Island at Namew Lake (Figure 1). Correlation of this lithologic sequence with that in cores SR1 and SR3 suggests that this outcrop includes the strata of the uppermost Herald and lower Stony Mountain Formations. Kupsch placed this entire section in the Stony Mountain Formation and correlated the lower argillaceous strata (Units 1 to 11) with argillaceous strata in the subsurface at the Gronlid No.1 well (15-32-47-17W2). However, correlation of well logs from Kendall's study area (e.g., 5-29-46-18W2) with the Gronlid No.1 well indicates that this argillaceous unit correlates with the Herald Formation as now defined in the subsurface in southern Saskatchewan. Accordingly, it appears that the lower 3.8 m (Units 1 to 11) at the Namew Island outcrop correlates with the Herald Formation and the upper 12.2 m (Units 12 to 18) with the Stony Mountain Formation.

Two outcrops at MacDonald's Bay on Namew Lake have been identified as strata of the Stonewall Formation (Sections 18 and 19 in Kupsch, 1952). The Gunton marker bed at the base of the Stonewall in SR1 and SR3 appears to correlate with Unit 6 in Section 18, as well as with Units 2(?) and 3 in Section 19.

The only known outcrop of Interlake strata is located at Pine Island on Cumberland Lake (Section 20 in

Kupsch, 1952) where the lithologies described in the thin (2.1 m) exposure are similar to those in the middle of the Strathclair subunit in cores SR1 and SR3.

4. Further Work

Much more information is required to fully understand Lower Paleozoic strata in the Cumberland Lake area. The four new cores (SR1, SR3, Ber3 and Ber4), when studied in detail and correlated with outcrops and other cores in Saskatchewan and Manitoba, should establish more definitive stratigraphic correlations. The information provided by well-preserved Interlake strata in the new cores will also greatly facilitate the author's ongoing study of the detailed stratigraphy and lithologies of Silurian strata in Saskatchewan.

5. References

Baillie, A.D. (1952): Ordovician geology of Lake Winnipeg and adjacent area, Manitoba; Manit. Dep. Mines Nat. Resour., Publ. 51-6, 64p.

Binda, P.L., Koopman, H.T. and Schwann, P.L. (1985): Sulphide ooids from the Proterozoic Siyeh Formation of Alberta, Canada; Mineral. Deposita, v20, p43-49.

Dunham, R.J. (1962): Classification of carbonate rocks according to depositional texture; *in* Ham W.E. (ed.), Classification of Carbonate Rocks; Am. Assoc. Petrol. Geol., Mem. 1, p108-121.

Embry, A.F. and Klovan, J.E. (1971): A Late Devonian reef tract on northeastern Banks Island, N.W.T.; Bull. Can. Petrol. Geol., v19, p730-781.

Haidl, F.M. (1987): Stratigraphic and lithologic relationships, Interlake Formation (Silurian), southern Saskatchewan; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p187-193.

Jamieson, E.R. (1979): Well data and lithologic descriptions of the Interlake Group (Silurian) in southern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 139, 67p.

Kendall, A.C. (1976): The Ordovician carbonate succession (Bighorn Group) of southeastern Saskatchewan; Sask. Miner. Resour., Rep. 180, 185p.

________ 1977: Origin of dolomite mottling in Ordovician limestones from Saskatchewan and Manitoba; Bull. Can. Petrol. Geol., v25, p480-504.

________ 1985: Depositional and diagenetic alteration of Yeoman (Lower Red River) carbonates from Harding Co., South Dakota; *in* Longman, M.W., Shanley, K.W., Lindsay, R.F. and Eby, D.E. (eds.), Rocky Mountain Carbonate Reservoirs - A Core Workshop; Soc. Econ. Paleon. Mineral., p95-124.

Kupsch, W.O. (1952): Ordovician and Silurian stratigraphy of east-central Saskatchewan; Sask. Dep. Miner. Resour., Rep. 10, 62p.

McCabe, H.R. (1984): Stratigraphic mapping and stratigraphic and industrial minerals core hole program; *in* Report of Field Activities 1984, Manit. Energy Mines, p136-143.

________ (1985): Stratigraphic mapping and stratigraphic and industrial minerals core hole program; *in* Report of Field Activities 1985, Manit. Energy Mines, p216-225.

________ (1987): Stratigraphic mapping and stratigraphic and industrial minerals core hole program; *in* Report of Field Activities 1987, Manit. Energy Mines, p151-161.

Paterson, D.F. (1971): The stratigraphy of the Winnipeg Formation (Ordovician) of Saskatchewan; Sask. Dep. Miner. Resour., Rep. 140, 57p.

The Red Jacket Formation of Southeastern Saskatchewan

L.K. Kreis

Kreis, L.K. (1988): The Red Jacket Formation of southeastern Saskatchewan; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

This report describes a proposed redefinition of part of the Jurassic stratigraphy in southeastern Saskatchewan. The need for a redefinition has arisen because of difficulties in attempting to extend stratigraphic picks of the Shaunavon Formation and upper member of the Gravelbourg Formation from their type area in southwestern Saskatchewan into southeastern Saskatchewan.

In an attempt to redress these difficulties and in conformity with the North American Stratigraphic Code (American Association of Petroleum Geologists, 1983, Article 23, Remark b), the author proposes the establishment of a new stratigraphic unit in the southeast, the Red Jacket Formation, which is separated by an arbitrary lithofacies cut-off from the Shaunavon Formation and upper member of the Gravelbourg Formation. The Red Jacket Formation is named after a village near the type section of the formation in the Tide Water North Wapella Crown 14-22-15-1 (Lsd. 14-22-15-1W2M) well.

Included in this report is a description and discussion of the type section, as well as the boundaries, distribution, lithology, age and correlation of the Red Jacket Formation. A west to east cross-section showing correlation of Jurassic strata between southwestern and southeastern Saskatchewan is included in the accompanying map package. A description of core from the type section is given in the Apppendix. This work is part of a broader study by the author of the oil-bearing Jurassic sandstones occurring at various levels in the Wapella–Moosomin area (Figure 2 and cross-section in map package).

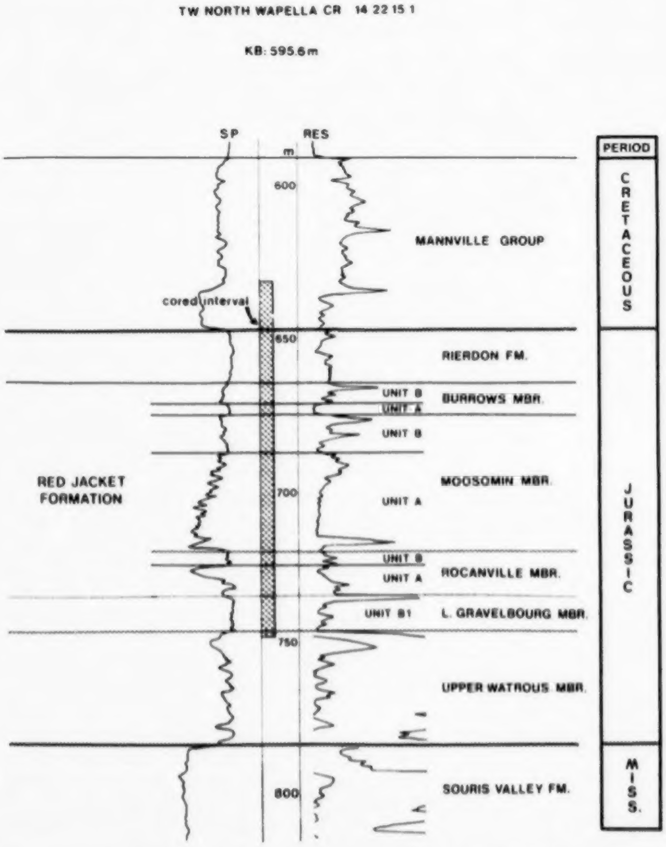

Figure 1 – Type section for the Red Jacket Formation in the TW North Wapella Crown 14-22-15-1 well, illustrating proposed stratigraphic subdivision and cored interval .

1. Stratigraphy

a) Type Section

The type section selected for the Red Jacket Formation is fully cored in the Tide Water North Wapella Crown well 14-22-15-1 (Lsd. 14-22-15-1W2M) between 2183.0 and 2452.0 ft. (665.4 and 747.4 m) below the Kelly Bushing (K.B.). This well exhibits the typical lithologies and geophysical well log responses common to the Red Jacket Formation and is the only well possessing a continuous core through all of the formation, as well as contiguous strata. The well is illustrated as number 14 in the cross-section (in map package). The cored interval in this well is illustrated in Figure 1.

Generally, recoveries of the 1.5 inch diameter wireline core of the Red Jacket Formation in the Tide Water North Wapella Crown well is fair (approx. 60 to 80 percent) to good (approx. 80 to 100 percent). However, a few intervals less than 10 ft. (3.0 m) in thickness demonstrate poorer recoveries. Unfortunately, the core is largely broken up due to repeated handling. Thus many contacts are not well preserved or are completely absent, especially in interlaminated and mudstone sections of the core.

The Red Jacket Formation has been divided into three members (Figure 1), all of them named after villages near their type section in the TW North Wapella Cr 14-22-15-1 well.

The lower member is herein named the Rocanville Member after the village in Twp. 16, Rge. 31W1. The Rocanville Member occurs in the type section for the Red Jacket Formation between 2360.0 and 2410.0 ft.(719.3 and 734.6 m).

The middle member is named the Moosomin Member after the town in Twp. 14, Rge. 31W1. The Moosomin Member is found in the type section for the Red Jacket Formation between 2215.3 and 2360.0 ft. (675.2 and 719.3 m).

The upper member is named the Burrows Member after the village in Twp. 15, Rge. 1W2. It occurs in the type section for the Red Jacket Formation between 2183.0 and 2215.3 ft. (665.4 and 675.2 m).

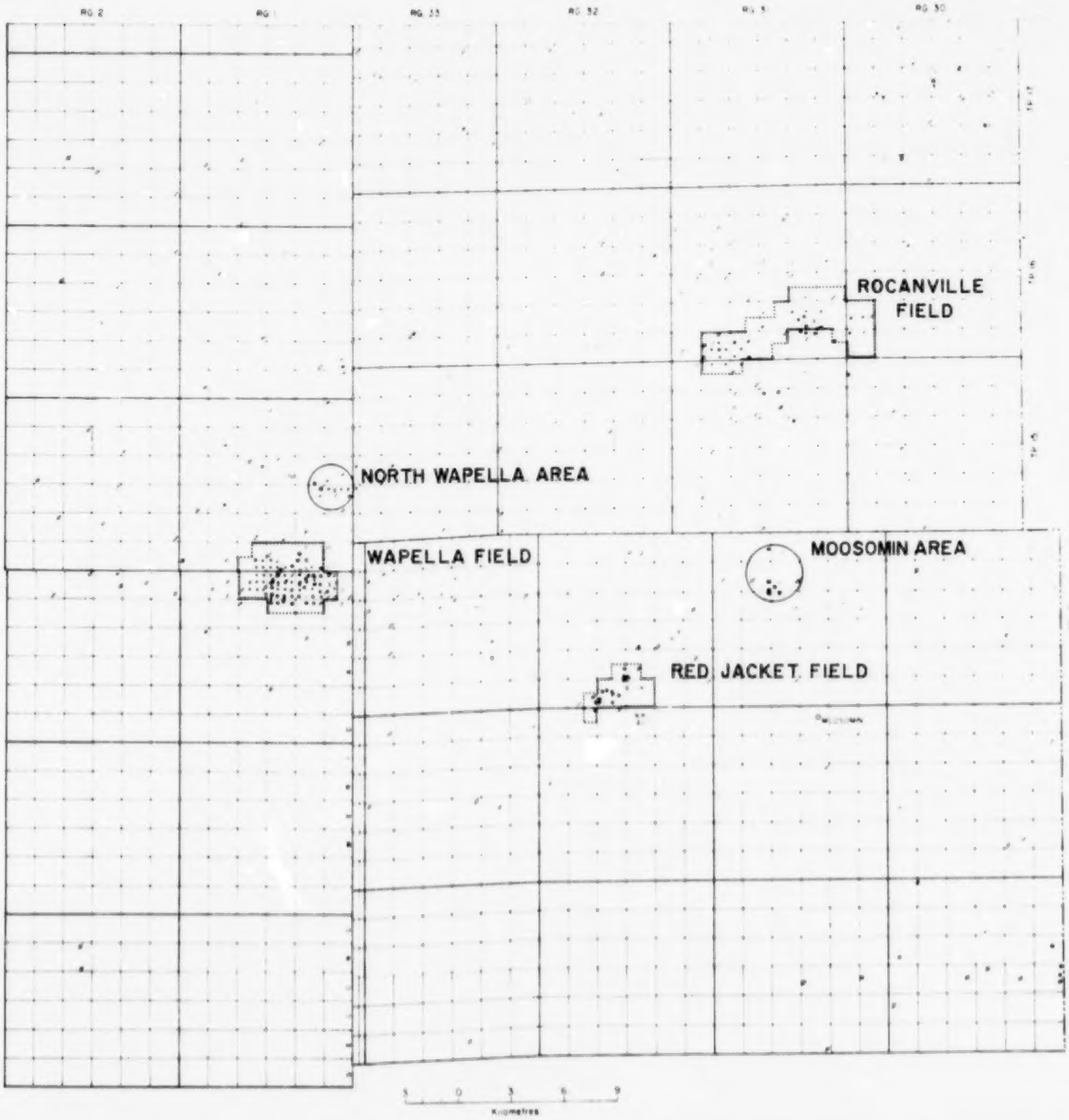
RG 2
RG 1
RG 33
RG 32
RG 31
RG 30
TP 17
TP 16
TP 15
TP 14
TP 13
TP 12
ROCANVILLE FIELD
NORTH WAPELLA AREA
WAPELLA FIELD
MOOSOMIN AREA
RED JACKET FIELD
3 0 3 6 9
Kilometres

Figure 2 - Location map of the study area referred to in the text as the Wapella-Moosomin area.

Discordances and apparent changes in lithofacies in some portions of the Red Jacket Formation complicate the correlation and recognition of these members. Distinctive lithologic characteristics of these members are best observed in core from the Wapella–Moosomin area of southeastern Saskatchewan (Figure 2).

Further subdivision of each of these members into a lower Unit A and an upper Unit B is at present restricted to the Wapella–Moosomin area, where there is sufficient well and core control. Subdivision using only log responses is hampered by 1) the similarity of lithologies between overlying and underlying units, 2) abrupt lithofacies changes, and 3) lateral variability in thickness as the result of numerous discordances which have locally thinned or completely removed individual units.

2. Definition of the Lower and Upper Boundaries

a) Definition of the Base

The base of the Red Jacket Formation occurs in the type section at 2410.0 ft. (734.6 m). Although this contact is missing in core from the type section, it is found to be sharp in other cores in the Wapella–Moosomin area. There appears to be a discontinuity between the Lower Gravelbourg Member and the overlying Rocanville Member of the Red Jacket Formation. The pick on a geophysical log is readily made in the Wapella–Moosomin area where porous sandstone of the Rocanville Member of the Red Jacket Formation rests on the limestone of the Lower Gravelbourg Member. This same contact however, is difficult to recognize in some wells to the south and west of this area due to a general lack of contrast in geophysical log responses with the underlying Lower Gravelbourg Member.

A similar lack of contrast is also locally present between the Lower and Upper Gravelbourg Members west of the arbitrary lithofacies boundary shown on the cross-section location map (in map package). For example, in wells 9 and 10 on the cross-section, slightly sandy limestones of the Lower Gravelbourg Member exhibit scarcely different SP/Res responses from the overlying silty, slightly calcite-cemented sandstones of the Upper Gravelbourg Member. The distinction between the Lower and Upper Gravelbourg Members originally proposed by Klingspor (1958, p. 34) has, in fact, never been formalized in southwestern Saskatchewan. It is only common usage which has brought about the subdivision of the Gravelbourg Formation into an upper and lower member. This lack of formalization has caused some confusion regarding the boundary between the Upper and Lower Members of the Gravelbourg Formation.

An unconformity at or near the top of what has been tentatively called the "Lower Gravelbourg" by Milner and Blakslee (1958) and other authors in southwestern Saskatchewan appears to have a counterpart in southeastern Saskatchewan. Vigrass (1952) noted the presence of a horizon of abundant bluish chalcedonic chert in what is currently regarded as the "Lower Gravelbourg" in southwestern Saskatchewan. He interpreted this horizon as an unconformity and used this interpretation to account for the variation in thickness of underlying strata. A similar horizon was also identified in southeastern Saskatchewan and southwestern Manitoba (Stott, 1955). Francis (1956), Klingspor (1958) and Kreis (1987) later adopted this "minor unconformity" or disconformity, which occurs at the top of a weathered dolomite with abundant bluish chalcedonic chert, as the pick for the top of the Lower Gravelbourg in southeastern Saskatchewan. It is noted that, in addition to bluish chalcedonic chert and weathered dolomite at this horizon, there are commonly euhedral bipyramidal quartz crystals.

The presence of chert and bipyramidal quartz has been interpreted as evidence for "vanished evaporites" (i.e., unpreserved evaporites) by Friedman (1980) in the Little Falls Dolostone (Late Cambrian) of Herkimer County, New York. In this locality, euhedral quartz crystals occur in vugs in dolomite, sandstone and associated stromatolitic dolomites. This observation is noted in connection with chalcedonic chert and euhedral bipyramidal quartz crystals found at the apparent unconformity in southwestern and southeastern Saskatchewan.

Detailed examination of drill cuttings and core makes it apparent that the chalcedonic chert-bearing horizon in southeastern Saskatchewan lies below a fossiliferous olive-grey (5Y4/1) calcareous mudstone, which in turn is overlain by or interbedded with an oolitic, very light grey (N8) to light olive-grey (5Y6/1) limestone. This mudstone and limestone unit is referred to in the cross-section (in map package) as Unit B1 of the Lower Gravelbourg Member in southeastern Saskatchewan. The underlying dolomitic limestone unit with weathered dolomite, chalcedonic chert and sporadic euhedral bipyramidal quartz at its top is referred to as Unit A1 of the Lower Gravelbourg in southeastern Saskatchewan.

Extensive geophysical log correlations appear to show that the mudstone and limestone of Unit B1 in southeastern Saskatchewan correlate with what was tentatively called "Lower Gravelbourg" in southwestern Saskatchewan by earlier stratigraphers (e.g., Milner and Blakslee, 1958). It would then appear that, although there is general agreement on the boundary between the Upper and Lower Gravelbourg Members in southwestern Saskatchewan, the top of the Lower Gravelbourg Member in southeastern Saskatchewan has been picked at a lower horizon, namely at the well-defined unconformity at the top of Unit A1. The acceptance of Unit B1 as the top of the Lower Gravelbourg Member in southeastern Saskatchewan is a revision of an earlier identification of the top of the Lower Gravelbourg Member (Kreis, 1987).

The cross-section (in map package) shows the suggested correlation and location of the apparent unconformity at the top of Unit A1 in southeastern Saskatchewan (i.e., wells 9 to 14). Defined by bluish-grey chalcedonic chert, weathered dolomite and sporadic euhedral bipyramidal quartz, it is interpreted to be the counterpart of the one illustrated in southwestern Saskatchewan (i.e., wells 1 to 3). In southwestern Saskatchewan, the Lower Gravelbourg Member is subdivided by this apparent unconformity into a Unit A and a Unit B. It is important to note that the presence of a cherty dolomite with or without euhedral quartz has not been observed in the intervening wells 4 to 8. A dashed line through these wells shows the suggested correlation between units of the Lower Gravelbourg Member in southwestern and southeastern Saskatchewan.

The presence of a horizon defined by bluish-grey chalcedonic chert, weathered dolomite and sporadic euhedral bipyramidal quartz in both southwestern and southeastern Saskatchewan is deemed to reflect an interlude of evaporitic to subaerial conditions before the return of marine conditions. The lack of evidence for an unconformity or evaporitic conditions in wells 4 to 8 may reflect the limit to which the Lower Gravelbourg sea receded.

b) Definition of the Top

The cross-section (in accompanying map package) shows that the top of the Red Jacket Formation occurs everywhere at the base of the calcareous mudstones of the Rierdon Formation. These mudstones commonly overlie a fossiliferous calcite-cemented sandstone subunit at the top of the Red Jacket Formation. Where this sandstone occurs, it is taken to be the uppermost portion of the uppermost unit, namely Unit B of the Burrows Member. This unit is generally composed of poorly sorted, very fine to fine-grained clear quartz sandstone. This sandstone is typically less than 1.5 m in thickness, light olive-grey (5Y6/1) in colour, silty, argillaceous and calcite cemented, and contains minor amounts of pyrite and a trace of glauconite. However, it is the abundance of well-worn *Gryphaea nebrascensis* and other pelecypod shell debris that characterizes this subunit. Christopher (1964) suggested that the presence of *G. nebrascensis* dates the sediment as Callovian in age, in which case this subunit would belong to the Rierdon Formation.

This calcite-cemented *Gryphaea*-bearing sandstone subunit is interpreted as a lag deposit at the base of the overlying Rierdon Formation and is therefore thought to lie unconformably on underlying strata. The presence of *G. nebrascensis* in this sandstone was not detected; however, where this sandstone is not highly calcite-cemented, it is indistinguishable on geophysical logs from underlying sandstones of the Red Jacket Formation. For these reasons, this sandstone subunit is placed in the uppermost portion of Unit B of the Burrows Member at the top of the Red Jacket Formation. For a more detailed discussion of the probable age and correlation of this subunit, the reader is referred to Christopher (1964, 1966) and Kreis (1987).

Where this uppermost sandstone subunit is not developed, an interbedded and burrow-mottled sandstone and mudstone sequence is found which is difficult to distinguish on geophysical logs from the overlying Rierdon Formation. In these instances, careful correlation with adjacent wells exhibiting more obvious contacts on geophysical logs, or use of available core, becomes necessary.

In the type section for the Red Jacket Formation in the Tide Water North Wapella Crown 14-22-15-1 well (Lsd. 14-22-15-1W2M), the calcite-cemented *Gryphaea*-bearing sandstone is present and the upper boundary for the Red Jacket Formation is taken to be at 2183 ft. (665.4 m) (Figure 1).

3. Distribution

The Red Jacket Formation occurs in southeastern Saskatchewan, east of the previously described arbitrary cutoff for the Shaunavon Formation and Upper Member of the Gravelbourg Formation. It extends eastward and southward, respectively, to the Manitoba and North Dakota borders, and to the north as far as the eroded edge of the Jurassic. The Red Jacket Formation was largely removed by erosion in the north half of the Wapella–Moosomin area during the Late Jurassic or Early Cretaceous. The areal distribution of the Red Jacket Formation is illustrated on the map accompanying the cross-section (in map package). The extent to which its subdivisions may be picked has not yet been defined.

The Red Jacket Formation varies in thickness from zero at its northern eroded edge (erosional edge of the Jurassic) to approximately 90 m in the Wapella–Moosomin area. In the Tricent et al. Coothill well (Lsd. 6-14-14-33W3M), the Red Jacket Formation is 88 m thick, due to an apparent thickening of Unit A of the Rocanville Member at the expense of Unit B1 of the Lower Gravelbourg Member (Figure 3). Other locally thickened sections have also been detected.

4. Lithology

The Red Jacket Formation comprises a complex succession of sandstones, siltstones, mudstones and minor carbonates. Sandstones and mudstones dominate, and are commonly interbedded and interlaminated. The Appendix gives a detailed core description of the type section for the Red Jacket Formation.

a) Rocanville Member

Unit A:

In the Wapella Field area, the base of Unit A comprises a slightly silty sandstone which directly overlies the limestones and calcareous mudstones of Unit B1 of the Lower Gravelbourg Member. In the type section log, the basal contact of Unit A occurs at 2410 ft. (734.6 m). Unfortunately, this contact is missing in the type section core, but in other wells in the area it is found to be sharp and locally erosional. Siltstone and interbeds of calcareous mudstone and argillaceous limestone also characterize Unit A of the Rocanville Member.

Unit B:

In the type section, the contact between Units A and B of the Rocanville Member is located at 2379.6 ft. (725.3 m). In the type section core, the overlying Unit B of the Rocanville Member consists of limey greenish-

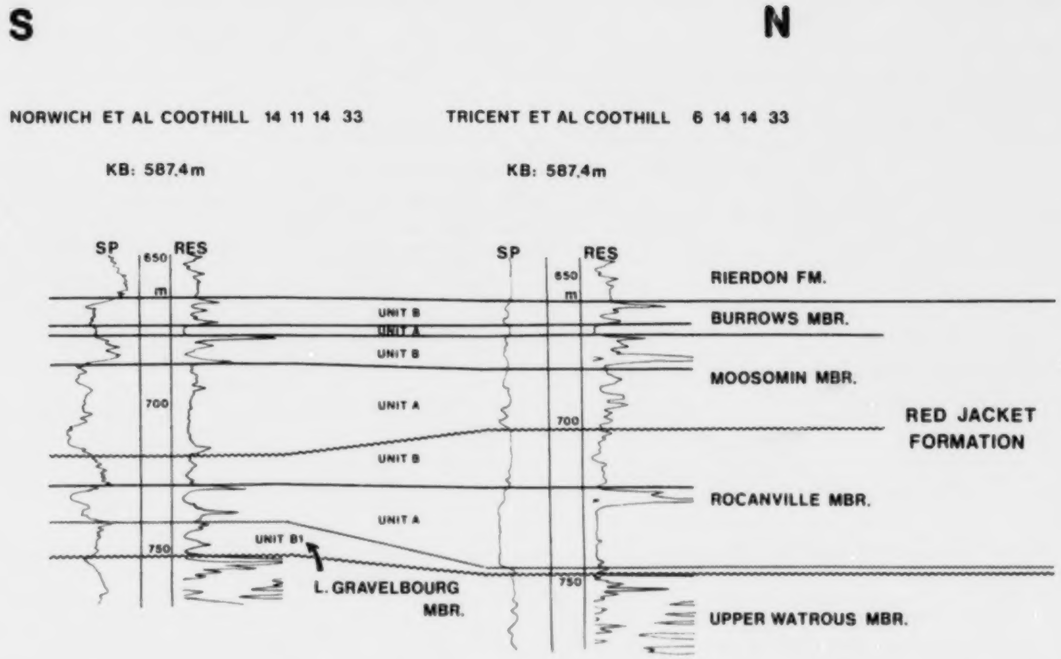

Figure 3 – North-south cross-section showing thickening in Unit A of the Rocanville Member at the expense of the underlying Unit B1 of Lower Gravelbourg Member.

grey (5GY6/1) mudstones which are typically dolomitic, and minor interbeds of yellowish-grey (5Y8/1) to light olive-grey (5Y6/1) and pale yellowish-brown (10YR6/2) limestone.

In many other wells in the Wapella–Moosomin area, the mudstones and argillaceous limestones present in the upper half of Unit B are very hard, dolomitic and quite variegated near the top. Colours vary from pale reddish brown (10R5/4) to moderate yellowish brown (10YR5/4) and greyish orange (10YR7/4).

b) Moosomin Member

A discontinuity appears to exist between the Rocanville Member and the overlying Moosomin Member. This contact is generally sharp and irregular, and the uppermost beds of Unit B of the Rocanville Member are typically dolomitic and variegated in shades of red and orange, colours commonly associated with sediments which have been subaerially exposed and subsequently oxidized.

The base of the Moosomin Member is found at 2360.0 ft. (719.3 m) in the type section for the Red Jacket Formation.

Unit A:

Unit A of the Moosomin Member is invariably thicker than the overlying Unit B. It is characterized by a sequence dominated by sandstone, mudstone and locally siltstone, and minor stringers of limestone. The sandstones of Unit A vary in colour from light olive grey (5Y6/1) to yellowish grey (5Y8/1) and, where oil stained, pale yellowish brown (10R6/2) to dark yellowish brown (10YR4/2). These sandstones are generally moderately sorted, composed of very fine to fine-grained, subangular to subrounded clear quartz, with trace to locally abundant amounts of pyrite, mica and carbonaceous fragments. They can also be variably cemented. Iron-carbonate nodules up to 6 cm across have also been observed in cores and large wood fragments have been intersected which span the entire cross-sectional surface of the core (i.e., 8 cm across).

These sandstones are commonly interbedded and interlaminated with noncalcareous to weakly calcareous, micaceous and carbonaceous olive-grey (5Y4/1) to medium grey (N5) mudstones. Perhaps the most distinctive characteristic of this unit is the occurrence of carbonaceous material and abundant, typically large (up to 1 mm across) mica flakes.

The contact between Units A and B of the Moosomin Member appears to be gradational, and is placed at 2257.0 ft. (687.9 m). The gradational nature of this contact and the similarity of lithologies between Units A and B make this subdivision difficult.

Unit B:

The Unit B rocks comprise greenish-grey (5GY6/1) to dark greenish-grey (5GY4/1) mudstones interbedded with yellowish-grey (5Y8/1) to light greenish-grey (5GY8/1) sandstones. The sandstones tend to consist of very fine to fine-grained, subangular to subrounded clear quartz with varying silt and argillaceous content. Mica and pyrite are important accessory minerals in Unit B, as in Unit A, but carbonaceous fragments are relatively scarce. The sandstones in Unit B tend to contain more cement than in Unit A. The mudstones are also more commonly calcareous than in Unit A, in places grading vertically into argillaceous limestones.

The upper 10 to 15 m of Unit B is generally characterized by a moderately to intensely bioturbated, interbedded and interlaminated sandstone/mudstone sequence. This bioturbation gives the interval a readily recognizable burrow-mottled texture. Locally, bioturbation has been so intense as to homogenize the sediment into sandy and virtually structureless rock.

c) Burrows Member

Unit A:

The base of the Burrows Member is defined by a sharp irregular contact, suggestive of a discontinuity, which in the type section occurs at 2215.3 ft. (675.2 m). At this contact, olive-grey (5Y4/1) to medium grey (N5) sandy mudstone or argillaceous sandstone commonly infills cracks in the underlying greenish-grey (5GY6/1) bioturbated sandstone/mudstone of Unit B of the Moosomin Member.

Unit A is characterized by olive-grey (5Y4/1) to medium grey (N5) claystone and mudstone. Generally, the lower 10 to 40 cm is a silty, micaceous, locally argillaceous and calcareous, very fine grained, clear quartz sandstone, which in many places is interlaminated with micaceous siltstone and argillaceous laminae. Sporadic interlaminations of micaceous and locally sandy siltstone are common near the base and the top of the unit. Numerous interlaminations of crushed thin-shelled pelecypods typically form pavements 1 to 2 mm thick throughout the unit.

Unit A is informally recognized by many workers in the Wapella-Moosomin area as the "Jurassic" or "Shaunavon" shale marker.

Where this unit has not been removed by a Late Jurassic to Early Cretaceous erosional event, it provides an invaluable and ubiquitous datum in the Red Jacket Formation.

Unit B:

The upper contact of Unit A is gradational into the overlying Unit B of the Burrows Member. Unit B represents a return to the bioturbated, interbedded and interlaminated, calcareous sandstone/mudstone lithofacies, similar to the upper 10 to 15 m of Unit B of the Moosomin Member. In the type section, the contact between Units A and B of the Burrows Member is defined at 2203.5 ft. (671.6 m), while the top of Unit B occurs at 2183.0 ft. (665.4 m).

The *Gryphaea*-bearing and poorly sorted sandstone subunit which commonly occurs at the top of the section is included in Unit B of the Burrows Member as discussed earlier (in section 2b).

5. Age and Correlation

The Red Jacket Formation of southeastern Saskatchewan is correlated with the Shaunavon Formation and the Upper Member of the Gravelbourg Formation in southwestern Saskatchewan (cross-section in map package).

The base of the Red Jacket Formation rests upon Unit B1 of the Lower Gravelbourg in southeastern Saskatchewan. The upper contact of the Red Jacket Formation is taken to be the base of the overlying light olive-grey (5Y6/1), calcareous mudstones of the Rierdon Formation. Fauna such as the oyster *G. nebrascensis* and the ammonite *Kepplerites* date the Rierdon Formation as Callovian (Christopher, 1964).

Imlay (1980) assigned a Bajocian age to the Gravelbourg Formation and the Lower Member of the Shaunavon Formation of southwestern Saskatchewan, and placed the Upper Shaunavon Member into the Bathonian. The Red Jacket Formation may therefore be assigned a Bajocian/Bathonian age. A possible exception to this age is the *Gryphaea*-bearing sandstone of the uppermost subunit of Unit B of the Burrows Member.

No flora or fauna which permit recognition of the Bajocian/Bathonian boundary have been identified in the Red Jacket Formation. A bioclastic limestone stringer capped with a coral rubble composed of well-worn pieces of the coral *Actinastrea* occurs, however, in the Moosomin Member of the Aberford Wapella 12A-34-14-1 well (Lsd. 12A-34-14-1W2M) at approximately 724.7 m. Paterson (1968, p. 14) recorded a basal conglomerate of the Upper Shaunavon in southwestern Saskatchewan as containing derived *Actinastrea*, suggesting that the Bajocian/Bathonian boundary in this well might lie at the top of the limestone stringer.

Imlay (1980, p.68-69) showed the Shaunavon Formation of southwestern Saskatchewan to be equivalent to the Bowes and Firemoon Limestone Members of the Piper Formation of northeastern Montana and northwestern North Dakota. He also correlated the Gravelbourg Formation of southwestern Saskatchewan with the Tampico Shale Member of the Piper Formation, and the Kline Member of the Nesson Formation in northeastern Montana and northwestern North Dakota. He also recognized an unconformity in the Gravelbourg Formation of southwestern Saskatchewan. In his correlation chart, Imlay (1980, p. 89-69) showed the Tampico Shale to be equivalent to Gravelbourg strata above an apparent unconformity defined by chert pebbles (Figure 4). This would appear to be the same unconformity observed between Units A and B of the Lower Gravelbourg Member in southwestern Saskatchewan, as was previously described (in section 2a).

Attempts at correlating the Red Jacket Formation with the Jurassic strata in Manitoba were unproductive. Although Stott (1955, p. 6) showed the Shaunavon and

Gravelbourg Formations of Saskatchewan to be equivalent to the Reston Formation of Manitoba, in another correlation chart (p. 36) in the same report, he showed the Reston to be equivalent to the Gravelbourg Formation and the Lower Shaunavon Member (J-2B) of the Shaunavon Formation.

It also appears that Francis (1956) was correct in his suggestion that Stott (1955) picked the Reston Formation stratigraphically much higher in east-central Saskatchewan than in southeastern Saskatchewan.

It would appear that inconsistencies in the definition and correlation of the Reston and Manitoba Formations in

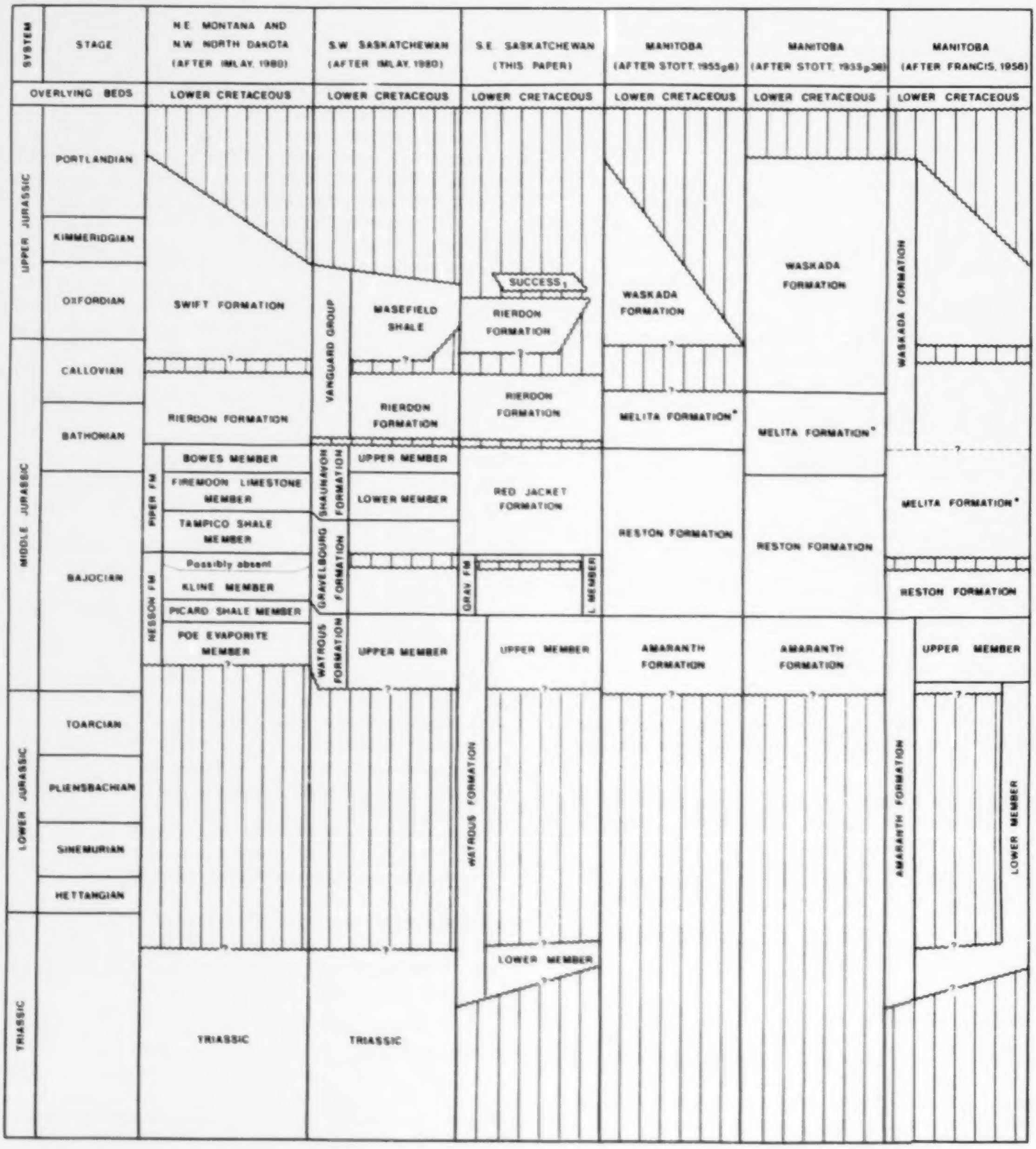
SYSTEM
STAGE
N.E. MONTANA AND N.W. NORTH DAKOTA (AFTER IMLAY, 1980)
S.W. SASKATCHEWAN (AFTER IMLAY, 1980)
S.E. SASKATCHEWAN (THIS PAPER)
MANITOBA (AFTER STOTT, 1955 p6)
MANITOBA (AFTER STOTT, 1955 p38)
MANITOBA (AFTER FRANCIS, 1956)
OVERLYING BEDS
LOWER CRETACEOUS
UPPER JURASSIC
MIDDLE JURASSIC
LOWER JURASSIC
TRIASSIC
PORTLANDIAN
KIMMERIDGIAN
OXFORDIAN
CALLOVIAN
BATHONIAN
BAJOCIAN
TOARCIAN
PLIENSBACHIAN
SINEMURIAN
HETTANGIAN
SWIFT FORMATION
RIERDON FORMATION
PIPER FM
BOWES MEMBER
FIREMOON LIMESTONE MEMBER
TAMPICO SHALE MEMBER
NESSON FM
Possibly absent
KLINE MEMBER
PICARD SHALE MEMBER
POE EVAPORITE MEMBER
TRIASSIC
VANGUARD GROUP
MASEFIELD SHALE
RIERDON FORMATION
SHAUNAVON FORMATION
UPPER MEMBER
LOWER MEMBER
GRAVELBOURG FORMATION
WATROUS FORMATION
UPPER MEMBER
TRIASSIC
SUCCESS
RIERDON FORMATION
RIERDON FORMATION
RED JACKET FORMATION
GRAV FM
L MEMBER
UPPER MEMBER
WATROUS FORMATION
LOWER MEMBER
WASKADA FORMATION
MELITA FORMATION*
RESTON FORMATION
AMARANTH FORMATION
WASKADA FORMATION
MELITA FORMATION*
RESTON FORMATION
AMARANTH FORMATION
WASKADA FORMATION
MELITA FORMATION*
RESTON FORMATION
UPPER MEMBER
AMARANTH FORMATION
LOWER MEMBER
?

Figure 4 – Stratigraphic correlation chart showing correlation of Red Jacket Formation with equivalent strata in conterminous areas. Note that the Melita and Reston Formations of Stott (1955, p. 6) are shown correlated with their lithostratigraphic equivalents, but Stott believes their contact to be the Bathonian/Callovian boundary.

Manitoba require resolution before their correlation with Saskatchewan strata can be understood. This is reflected in the correlation chart in Figure 4.

6. References

American Association of Petroleum Geologists (1983): North American Stratigraphic Code; Bull. Am. Assoc. Petrol. Geol., V67, p841-875.

Christopher, J.E. (1964): The Middle Jurassic Shaunavon Formation of southwestern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 95, 95p.

________ (1966): The Middle Jurassic Shaunavon Formation of southwestern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 110, 308p.

Francis, D.R. (1956): Jurassic stratigraphy of the Williston basin area; Sask. Dep. Miner. Resour., Rep. 18, 69p.

Friedman, G.M. (1980): Dolomite is an evaporite mineral: evidence from the rock record and from sea-marginal ponds of the Red Sea; Soc. Econ. Paleon. Mineral., Spec. Publ. 28., p69-80.

Imlay, R.W. (1980): Jurassic paleobiogeography of the conterminous United States in its continental setting; U. S. Geol. Surv., Prof. Pap. 1002, 134p.

Klingspor, A.M. (1958): Jurassic stratigraphy of the Sweetgrass Arch – Manitoba section; *in* Goodman, A.J. (ed.), Jurassic and Carboniferous of Western Canada; Am. Assoc. Petrol. Geol., John Andrew Allen Mem. Vol., p27-51.

Kreis, L.K. (1987): Regional stratigraphic correlation and lithology of the Jurassic, Wapella – Moosomin area, southeastern Saskatchewan; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p176-186.

Milner, R.L. and Blakslee, G.W. (1958): Notes on the Jurassic of southwestern Saskatchewan; *in* Jurassic and Carboniferous of Western Canada; Am. Assoc. Petrol. Geol., John Andrew Allan Mem. Vol., p65-84.

Paterson, D.F. (1968): Jurassic megafossils of Saskatchewan with a note on *Charophytes*; Sask. Dep. Miner. Resour., Rep. 120, 135p.

Payne, T.G. (1942): Stratigraphical analysis and environmental reconstruction; Bull. Am. Assoc. Petrol. Geol., v26, p1697-1770.

Stott, D.F. (1955): The Jurassic stratigraphy of Manitoba; Manit. Dep. Mines Nat. Resour., Mines Br. Publ. 54-2.

Vigrass, L.W. (1952): Jurassic stratigraphy of Saskatchewan; unpubl. M.Sc. thesis, Univ. Sask.

7. Appendix A

The following core description is for the type section of the Red Jacket Formation in the Tide Water North Wapella Crown 14-22-15-1 well, and includes strata immediately above and below.

Intervals are given in feet below K.B., with the metric equivalent in parentheses on the line beneath. The figure on the third line is the length of the interval in metres.

The grading scale for grain size of sandstone and mudstone is based on the Wentworth scale as follows:

Size Class	Grain Diameter
Very coarse grained	2 to 1 mm
Coarse grained	1 to 0.5 mm
Medium grained	0.5 to 0.25 mm
Fine grained	0.25 to 0.125 mm
Very fine grained	0.125 to 0.06 mm
Silt	0.06 to 0.004 mm
Clay	0.004 mm or less

The sorting classification used follows Payne (1942), who employed Wentworth size classes:

Well sorted	90 percent in 1 or 2 size classes
Moderately sorted	90 percent in 3 or 4 size classes
Poorly sorted	90 percent in 5 or more size classes

The Geological Society of America (second printing, 1951) colour chart was used.

The term "laminae" in this report refers to layers less than 1 cm in thickness, while "bed" refers to layers 1 cm thick or greater.

The following terms are used as a measure of mineral and fossil abundance:

Abundant	greater than 10 percent
Minor	1 to 10 percent
Trace	less than 1 percent

Tide Water North Wapella Crown 14-22-15-1W2

K.B: 1954 ft.(595.6 m)

Jurassic

Rierdon Formation top	2120 ft. (646.2 m)
Red Jacket Formation:	
Burrows Member top	2183 ft. (665.4 m)
Moosomin Member top	2214 ft. (674.8 m)
Rocanville Member top	2360 ft. (719.3 m)
Gravelbourg Formation:	
Lower Gravelbourg Member top	2410 ft. (734.6 m)
Watrous Formation:	
Upper Watrous Member top	2451 ft. (747.1 m)

Mississippian

Souris Valley Formation top	2572 ft. (783.9 m)

Jurassic

Rierdon Formation

2161.0-2183.0 (658.7-665.4) (Rec. 5.2 m)	Mudstone: light olive grey (5Y6/1), slabby parting, hard, highly calcareous, trace to minor amounts of disseminated pyrite, fossiliferous. A sparse assemblage of belemnites, pelecypods (*Gryphaea nebrascensis*), ostracodes and am-

monite shell fragments (*Kepplerites*?). Locally, mudstone grades abruptly into claystone or siltstone beds up to 1.5 m thick.
Lower contact missing.

Red Jacket Formation

Burrows Member

2183.0-2189.0 (665.4-667.2) (Rec. 0.91 m)	Sandstone: light olive grey (5Y6/1), hard, very fine to fine grained, subangular to subrounded, clear quartz, poorly sorted, calcite cemented, silty, slightly argillaceous with minor amounts of very fine disseminated pyrite, a trace of glauconite and abundant broken-up well-worn *Gryphaea nebrascensis* and other unidentified pelecypod shells. Lower contact not preserved.
2189.0-2191.0 (667.2-667.8) (Rec. 0.23 m)	Mudstone: greenish grey (5GY6/1) to dark greenish grey (5GY4/1), hard, slabby parting, slightly calcareous to locally highly calcareous. Locally, abundant pelecypod molds (possibly *Pleuromya oblongata* and *P. simplex*?). Lower contact missing.
2191.0-2194.1 (667.8-668.8) (Rec. 0.92 m)	Mudstone: greenish grey (5GY6/1), hard, slabby parting, slightly calcareous, swelling clays, abundant molds of pelecypods and the occasional ostracode. Moderately laminated with lenticular and parallel laminations of micaceous silt. Lower contact missing.
2194.1-2196.5 (668.8-669.5) (Rec. 0.73 m)	Sandstone: bioturbated, mottled, greenish grey (5GY6/1) to light olive grey (5Y6/1), hard, very fine to fine grained, clear quartz, subangular to subrounded, moderately sorted, well cemented with calcite, locally abundant pelecypods. Locally abundant fine-grained disseminated pyrite. Very fine grained pyrite locally replaces pelecypod shells. Disturbed greenish grey (5GY6/1) calcareous mudstone laminations common over lower third. Lower contact sharp.
2196.5-2199.5 (669.5-670.4) (Rec. 0.80 m)	Mudstone: greenish grey (5GY6/1), hard, slabby parting, calcareous. In gradational contact with interlaminated, silty sandstone below.
2199.5-2203.5 (670.4-671.6) (Rec. 1.20 m)	Sandstone: moderately to intensely bioturbated, highly interlaminated with mudstone and siltstone, light olive grey (5Y6/1), moderately friable, moderately sorted, very fine grained, subangular, clear quartz, slightly calcareous, very silty (up to 30 percent), minor amounts of mica, slightly argillaceous, trace of indeterminate bone fragments and occasional poorly preserved pelecypod shell. Local patches of minor amounts of very fine grained disseminated pyrite. Occasional sandy, calcite infilled, vertical fractures < 1 mm across. Lower contact gradational.
2203.5-2215.3 (671.6-675.2) (Rec. 3.60 m)	Claystone: medium grey (N5) to olive grey (5Y4/1), hard, slabby to flaggy parting, locally slightly calcareous, occasional parallel lamination of abundant pelecypod shells (possibly *P. oblongota* and *P. simplex*?). Occasional parallel laminations of micaceous silt and locally very fine grained clear quartz. Sandy, olive grey (5Y4/1) mudstone from this interval infills crack in the underlying greenish grey (5GY6/1) unit. Lower contact sharp.

Moosomin Member

2215.3-2226.9 (675.2-678.8) (Rec. 3.00 m)	Sandstone (80 percent) and Mudstone (20 percent): moderately to intensely bioturbated, intermixed, mottled, light greenish grey (5GY8/1) to greenish grey (5GY6/1). Sandstone is hard, comprising, very fine to fine grained, subangular to subrounded clear quartz, locally abundant poorly preserved pelecypods and trace amounts of mica and indeterminate fish fragments. Moderately sorted, argillaceous (<5 percent), silty (<5 percent) and well-cemented with calcite. Locally abundant disseminated pyrite and occasional nodules up to 2 cm across. Mudstone is greenish grey (5GY6/1), hard, with slabby partings, locally abundant pelecypods, high calcite content and up to 30 percent scattered, very fine to fine-grained clear quartz. Patchy, pale yellowish-brown (10YR6/2) oil-staining over lower 30 cm. Lower contact gradational.
2226.9-2231.0 (678.8-680.0) (Rec. 0.96 m)	Mudstone: interlaminated, greenish grey (5GY6/1) to dark greenish grey (5GY4/1), hard, slabby parting, calcareous. Laminated with micaceous siltstone and silty, micaceous, very fine to fine-grained clear quartz sandstone which locally exhibits pale yellowish-brown (10YR6/2) oil-staining. Lower contact missing.
2231.0-2237.0 (680.0-681.8) (Rec. 1.47 m)	Mudstone: moderately bioturbated, mottled, yellowish grey (5Y8/1) to greenish grey (5GY6/1). Mudstone is hard, calcareous, with the occasional pelecypod mold and traces of mica and fine-grained disseminated pyrite. Limestone bed from approximately 2231.5 to 2232.1 (680.16 to 680.34 m). This limestone is very sandy and bioturbated over upper half, argillaceous, highly fossiliferous

	(abundant pelecypod shells), peloidal (indeterminate carbonate grains <1 mm across) with traces of unidentified bone fragments and patches of very fine grained disseminated pyrite <0.5 cm across. Mudstone is gradational with argillaceous, silty, micaceous, poorly sorted, very fine grained sandstone over lower 40 cm. Lower contact missing.
2237.0-2243.5 (681.8-683.8) (Rec. 1.43 m)	Sandstone: yellowish grey (5Y8/1) to greenish grey (5GY6/1), hard, very fine to fine grained, subangular to subrounded, clear quartz, argillaceous, silty, trace of mica, trace of very fine grained disseminated pyrite. Small-scale ripples are observed at several intervals. Mudstone interbed from approximately 2239.5 to 2240.5 (682.6 to 682.9 m). The mudstone is greenish grey (5GY6/1), slightly dolomitic and exhibits trace amounts of mica. Lower contact of unit gradational.
2243.5-2257.0 (683.8-687.9) (Rec. 3.11 m)	Mudstone: greenish grey (5GY6/1), hard, slabby parting, slightly calcareous to calcareous, trace of mica, trace of pyrite, trace of indeterminate fish(?) bone fragments. Moderately bioturbated sandstone interbeds up to 40 cm thick found between approximately 2247.0 and 2251.0 (684.9 and 686.1 m). Sandstone is composed of very fine to fine-grained clear quartz, is well cemented with calcite, slightly argillaceous, silty (up to 30 percent) with trace amounts of pyrite, carbonaceous fragments and indeterminate bone fragments. Lower contact gradational.
2257.0-2292.0 (687.9-698.6) (Rec. 6.40 m)	Sandstone (60 percent) and Mudstone (40 percent): interbedded and interlaminated. Sandstone is yellowish grey (5Y8/1) to dusky yellowish brown (10YR2/2) where oil stained. It is hard, moderately to poorly sorted, made up of very fine to fine-grained, subangular to subrounded clear quartz. It is variably calcite cemented, silty (up to 30 percent) and slightly argillaceous (<3 percent), with trace amounts of mica (flakes up to 1 mm thick), pyrite (nodules up to 3 mm across) and carbonaceous fragments. Sandstone is interlaminated and interbedded with greenish-grey (5GY6/1) to olive-grey (5Y4/1) mudstone. The mudstone is locally slightly calcareous, sandy (up to 30 percent very fine to fine-grained clear quartz) and highly interlaminated with siltstone and silty, micaceous, very fine grained sandstone. Mudstone interbeds range up to 90 cm in thickness. Silty, micaceous and carbonaceous laminations become increasingly common over lower 3 metres. Lower contact very gradational.
2292.0-2306.0 (698.6-702.9) (Rec. 3.17 m)	Sandstone (70 percent) and Mudstone (30 percent): interbedded and interlaminated. Sandstone ranges in color from yellowish grey (5Y8/1) to light olive grey (5Y6/1) and dark yellowish brown (10YR4/2) where oil stained. The sandstone is generally friable but local calcite cemented zones up to 15 cm thick are observed. It is moderately sorted, containing very fine to fine-grained, subangular to subrounded clear quartz, with locally abundant mica and carbonaceous fragments, and trace amounts of pyrite. Abundant interlaminations of argillaceous, silty, micaceous and slightly carbonaceous sandstone and occasionally olive grey (5Y4/1), sandy mudstone. Mudstone interbeds up to 30 cm in thickness with abundant interlaminations of silty, micaceous and carbonaceous, very fine grained clear quartz. The mudstone itself has as much as 40 percent scattered, very fine grained clear quartz. Lower contact missing.
2306.0-2317.0 (702.9-706.2) (Rec. 1.92 m)	Sandstone: yellowish grey (5Y8/1) with oil-stained patches of dark yellowish brown (10YR4/2). It is moderately friable, moderately to well sorted, composed of very fine to fine-grained, subangular to subrounded clear quartz. There are trace amounts of fine grained disseminated pyrite, mica and carbonaceous fragments. Locally, abundant interlaminations of argillaceous, silty, micaceous and carbonaceous material. There are occasional interbeds of sandy (up to 30 percent very fine to fine grained, clear quartz) olive grey (5Y4/1) mudstone of less than 15 cm thickness. Lower contact missing.
2317.0-2323.0 (706.2-708.1) (Rec. 0.82 m)	Sandstone: interlaminated, yellowish grey (5Y8/1) to pale yellowish brown (10YR6/2) where oil stained. It is friable, moderately to poorly sorted, containing very fine to fine grained, subangular to subrounded clear quartz with up to 30 percent silt and minor quantities of mica and carbonaceous fragments. Interlaminations of highly argillaceous, micaceous and carbonaceous material are common. Lower contact missing.
2323.0-2349.0 (708.1-716.0) (Rec. 4.58 m)	Sandstone: yellowish grey (5Y8/1) to pale yellowish brown (10YR6/2) where oilstained. It is friable, moderately to well sorted, composed of very fine to fine-grained, subangular to subrounded clear quartz. Generally it is silty (up to 20 per-

	cent) with minor mica (flakes up to 1 mm across) and trace amounts of fine-grained disseminated pyrite and carbonaceous fragments. Locally, there are parallel to wavy interlaminations of slightly argillaceous, micaceous and carbonaceous material. Sandy, micaceous and carbonaceous mudstone interbeds measuring up to 10 cm thick are common between approximately 2328.0 and 2338.0 (709.6 and 712.6 m). Locally, these mudstones are interlaminated with silty, micaceous sandstone. Lower 40 cm also interbedded with olive-grey (5Y4/1) mudstone up to 10 cm thick. Lower contact missing.
2349.0-2360.0 (716.0-719.3) (Rec. 2.29 m)	Sandstone: light olive grey (5Y6/1) to dark yellowish brown (10YR4/2) in patchy oil-stained areas. Sandstone is hard to moderately friable, well sorted, composed of very fine to fine-grained, subangular to subrounded clear quartz with trace to minor amounts of mica and carbonaceous fragments (with the occasional carbonaceous wood fragment up to 4 cm across). It is well cemented with calcite over upper half, exhibiting high angle planar (up to 20°) and current ripple bedding. Laminations are defined by abundant mica (flakes up to 1 mm across) and organic detritus. Lower contact missing.

Rocanville Member

2360.0-2364.5 (719.3-720.7) (Rec. 0.61 m)	Mudstone: greenish grey (5GY6/1), hard, slabby parting, moderately to locally highly calcareous, sandy (up to 10 percent scattered very fine to fine grained quartz). A 2 cm thick layer of calcite and slightly oxidized, pyrite-cemented, poorly sorted, fine-grained, subrounded clear quartz sandstone occurs at the top of the material recovered in this interval. This sandstone layer is cemented with calcite and slightly oxidized pyrite. Lower contact is sharp and irregular.
2364.5-2373.5 (720.7-723.4) (Rec. 2.29 m)	Limestone: yellowish grey (5Y8/1) to light olive-grey (5Y6/1), very hard, dolomitic, highly argillaceous, slightly sandy (up to 5 percent scattered, very fine to fine grained clear quartz). Dark greenish-grey (5GY4/1) calcareous mudstone break between approximately 2367.5 and 2369.0 (721.6 and 722.1 m). Upper contact displays a 10 cm long vertical fracture infilled with overlying greenish grey (5GY6/1) mudstone. Lower contact sharp.
2373.5-2376.0 (723.4-724.2) (Rec. 0.46 m)	Mudstone: greenish grey (5GY6/1), hard, slabby parting, calcareous, sandy (up to 5 percent scattered, very fine to fine grained, clear quartz). Lower contact missing.
2376.0-2378.4 (724.2-724.9) (Rec. 0.74 m)	Limestone: pale yellowish brown (10YR6/2), very hard, dolomitic, slightly argillaceous, trace to minor amounts of pyrite (commonly in patches <0.5 cm across), traces of mica and scattered, very fine grained clear quartz. A few poorly preserved pelecypod shells and a trace of indeterminate fish(?) bone fragments are also present. Lower contact gradational.
2378.4-2379.6 (724.9-725.3) (Rec. 0.34 m)	Mudstone: greenish grey (5GY6/1), hard, slabby parting, becomes increasingly calcareous towards top, one large (4 cm across) mold of pelecypod shell fragment and trace amounts of indeterminate bone fragments. Occasional laminations of silty, micaceous, very fine to fine grained, subangular to subrounded, clear quartz. Lower contact poorly preserved.
2379.6-2390.0 (725.3-728.5) (Rec. 1.89 m)	Sandstone: yellowish grey (5Y8/1) to dark yellowish brown (10YR4/2) in small (<3 cm) patches of oil staining. It is moderately friable, moderately to well sorted, containing fine-to medium-grained, subangular to subrounded, slightly calcite-cemented clear quartz with trace to minor amounts of mica. Excellent porosity in a well-sorted medium-grained interval between approximately 2383.0 and 2385.0 (726.3 and 727.0 m). Becomes siltier and finer grained above and below this interval. In gradational contact with underlying sandstone.
2390.0-2395.5 (728.5-730.1) (Rec. 1.07 m)	Sandstone and Siltstone: interlaminated, interbedded, yellowish grey (5Y8/1) to light olive grey (5Y6/1), moderately hard. Sandstone is moderately hard, moderately sorted, slightly calcite cemented, composed of very fine grained, subangular clear quartz with abundant silt (up to 50 percent), minor amounts of mica and an occasional pyrite nodule (up to 1.5 cm across). Abundant interlaminations and interbeds of sandy (up to 30 percent very fine grained clear quartz), argillaceous siltstone over lower two-thirds. Lower contact gradational.
2395.5-2397.7 (730.1-730.8) (Rec. 0.55 m)	Mudstone: olive grey (5Y4/1), hard, slabby parting, trace amounts of very fine grained disseminated pyrite, carbonaceous fragments and indeterminate bone fragments. Becomes calcareous over lower 15 cm. Lower contact missing.

2397.7-2400.0 (730.8-731.5) (Rec. 0.65 m)	Sandstone: white (N9) to yellowish grey (5Y8/1), moderately friable, moderately calcite cemented, very fine grained, subangular, clear quartz, showing a trace of mica and locally abundant pyrite nodules (nodules up to 3 cm across present over lower half). Becomes increasingly interlaminated with very silty and slightly argillaceous material over lower two-thirds. Lower contact sharp.
2400.0-2401.5 (731.5-732.0) (Rec. 0.15 m)	Mudstone: greenish grey (5GY6/1), hard, slabby parting, calcareous with a trace of pyrite and very fine grained, scattered quartz. Lower contact of unit missing.
2401.5-2403.0 (732.0-732.4) (Rec. 0.34 m)	Limestone: light olive grey (5Y6/1) to yellowish grey (5Y8/1), hard, dolomitic and argillaceous, with trace amounts of mica and very fine grained disseminated pyrite. Grades up from a calcareous greenish-grey (5GY6/1) mudstone over lower 15 cm. Lower contact missing.
2403.0-2405.2 (732.4-733.1) (Rec. 0.82 m)	Limestone: yellowish grey (5Y8/1), hard, dolomitic, slightly argillaceous, locally abundant bean-shaped ostracodes and trace amounts of mica and pyrite. Lower contact of unit gradational.
2405.2-2406.9 (733.1-733.6) (Rec. 0.52 m)	Siltstone: greenish grey (5GY4/1), hard, slabby parting, argillaceous, minor to locally abundant mica and sandy (up to 30 percent very fine grained clear quartz). Lower contact gradational.
2406.9-2410.0 (733.6-734.6) (Rec. 0.91 m)	Sandstone: interlaminated, yellowish grey (5Y8/1), moderately hard and moderately to poorly sorted. Consists of very fine grained, subangular clear quartz and is argillaceous, very silty (locally up to 40 percent) with minor to abundant mica and a trace of carbonaceous fragments over lower half. Grades into a siltstone over lower 30 cm. Lower contact missing.

Lower Gravelbourg

2410.0-2410.7 (734.6-734.8) (Rec. 0.20 m)	Limestone: olive grey (5Y4/1), very hard. This limestone is dominated by ovate to subspherical peloids up to 2 mm in length and 1 mm across. The peloids contain significant amounts of silt-sized pyrite. The limestone matrix is slightly argillaceous with minor pyrite and a trace of mica. The uppermost 1.5 cm interval contains calcareous, olive-grey (5Y4/1) mudstone and rounded, medium- to coarse-grained olive-black (5Y2/1) carbonate grains (peloids), silt (approximately 20 percent) and trace amounts of glauconite in an olive-grey (5Y4/1) matrix. This is immediately underlain by a 2 to 3 mm layer of fibrous calcite and pyrite. Lower contact of unit sharp.
2410.7-2416.5 (734.8-736.6) (Rec. 1.77 m)	Limestone: light olive grey (5Y6/1), very hard, slightly argillaceous with trace amounts of mica and scattered, very fine grained clear quartz. Becomes increasingly interlaminated over lower half with silty, slightly argillaceous laminae with abundant silt-sized disseminated pyrite. Lower contact sharply defined by a 0.5 cm band of interlaminated, peloidal and sandy (up to 30 percent very fine to fine-grained clear quartz) mudstone with abundant disseminated pyrite and trace amounts of mica and glauconite.
2416.5-2431.5 (736.6-741.1) (Rec. 2.92 m)	Mudstone: olive grey (5Y4/1), hard, platy to fissile parting, calcareous with abundant thin-shelled pelecypods <0.5 cm across. Pelecypods so abundant as to form laminae <1.0 mm thick which consist entirely of crushed shells. An interbed of olive grey (5Y4/1), highly fossiliferous (abundant pelecypods), sandy (up to 20 percent very fine grained clear quartz) limestone with abundant very fine grained disseminated pyrite and a trace of mica and glauconite occurs between approximately 2421.5 and 2422.0 (738.1 and 738.2 m). Lower contact sharp, defined by a 10 cm band of highly fossiliferous (pelecypod shell hash), glauconitic, peloidal, pyritic and sandy (up to 10 percent very fine to fine grained clear quartz) mudstone at base.
2431.5-2432.2 (741.1-741.32) (Rec. 0.22 m)	Limestone: light olive grey (5Y6/1), very hard and massive. Occasional vertical hairline fracture lined with very fine grained pyrite. Lower contact sharp and irregular, defined by a 1.5 cm thick band of calcite- and pyrite-cemented, fine-grained argillaceous sandstone at the top of the underlying mudstone.
2432.2-2434.0 (741.1-741.9) (Rec. 0.61 m)	Mudstone: light olive grey (5Y6/1), hard, silty to locally sandy (up to 40 percent very fine grained clear quartz) with minor very fine grained disseminated pyrite and trace amounts of mica and glauconite. Lower contact of unit missing.
2434.0-2437.0 (742.2-742.8) (Rec. 0.55 m)	Sandstone: light olive grey (5Y6/1), hard and moderately sorted. It consists of very fine grained, subangular to subrounded clear quartz and is calcite cemented. Has minor amounts of mica, very fine grained disseminated pyrite (occasional patch <0.5 cm across) and a trace of carbonaceous fragments. It becomes increasingly argillaceous and silty towards

base.
Lower contact appears gradational.

2437.0-2440.0 (742.8-743.7) (Rec. 0.46 m) Mudstone: greenish grey (5GY6/1), hard, slabby parting, moderately calcareous, sandy (up to 30 percent very fine to fine grained clear quartz), with minor mica and trace amounts of carbonaceous fragments and disseminated pyrite.
Lower contact missing.

2440.0-2444.0 (743.7-744.9) (Rec. 1.07 m) Siltstone: light olive grey (5Y6/1), hard, calcareous, argillaceous with traces of mica and pyrite. Calcareous, greenish-grey (5GY6/1) mudstone break between approximately 2441.0 and 2441.5 (744.0 and 744.2 m).
Lower contact of unit gradational.

2444.0-2451.5 (744.9-747.2) (Rec. 0.91 m) Mudstone: light olive grey (5GY6/1), hard, flaggy parting, highly calcareous (approaching limestone composition).
Lower contact of unit not preserved.

2451.5-2452.0 (747.2-747.4) (Rec. 0.23 m) Sandstone: greenish grey (5GY6/1), moderately hard, moderately to poorly sorted, very fine to fine grained, clear quartz, argillaceous, silty (up to 30 percent), minor mica, minor to locally abundant glauconite and pyrite, minor subrounded very pale orange (10YR8/2) carbonate fragments and trace to minor amounts of greyish blue (5PB5/2) to dusky blue (5PB3/2) subrounded to rounded chalcedonic chert nodules up to 3 mm across.
Lower contact of unit sharp and irregular.

Upper Watrous Member

2452.0-2459.0 (747.4-749.5) (Rec. 0.31 m) Dolomite and Anhydrite: interbedded. Dolomite is very pale orange (10YR8/2) to light olive grey (5Y6/1), while the anhydrite is light bluish grey (5B7/1) to light grey (N7). Dolomite is massive, brecciated, with fractures infilled by gypsum. Interbeds consisting of light bluish-grey (5B7/1) to light grey (N7) anhydrite intermixed with greyish-blue (5PB5/) to dusky blue (5PB3/2) chalcedonic chert. Locally euhedral, bipyramidal quartz crystals and chalcedonic chert nodules occur as apparent void-fill in the dolomite.
Very poor recovery.

Review of Regional Stratigraphic Relationships of the Winnipeg Group (Ordovician), the Deadwood Formation (Cambro-Ordovician) and Underlying Strata in Saskatchewan

D.F. Paterson

Paterson, D.F. (1988): Review of regional stratigraphic relationships of the Winnipeg Group (Ordovician), the Deadwood Formation (Cambro-Ordovician) and underlying strata in Saskatchewan; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

The lowermost Phanerozoic rocks in southern Saskatchewan and adjoining areas to the east, west and south comprise a sequence of interbedded sandstones, siltstones and shales underlying carbonates of the Ordovician Red River Formation. Dowling (1900) and Darton (1901) reported on outcrops of the sequence from Lake Winnipeg and Black Hills respectively, and numerous later studies included much subsurface data from areas where deep wells had been drilled (see, most recently, Anderson (1988) for North Dakota and, for a comprehensive list of references, Lefever et al. (1987)).

The uppermost strata of the sequence in Saskatchewan form the Winnipeg Formation, which has a maximum thickness of 67 m. Paterson (1971) subdivided it into a lower Black Island Member and an upper Icebox Member, and documented their stratigraphic and areal extents. His subdivisions agreed essentially with those of Carlson (1960) who recognized a third uppermost member called the Roughlock. Carlson's proposal that a thin band of the Roughlock extends into extreme southeast Saskatchewan has not so far been confirmed. Carlson and Anderson (1965) raised the Winnipeg to group status and the members to formations.

In Manitoba, Vigrass (1971) and McCabe (1978) similarly defined the Winnipeg Formation but subdivided it into Upper and Lower Units.

There is general agreement that the Winnipeg Formation is Middle Ordovician in age (Lefever et al. (1987) specify Caradocian) and rests uncomformably upon the underlying strata. In the eastern part of southern Saskatchewan, it directly overlies Precambrian metamorphic rocks. In the west, towards the Alberta border, it overlies a wedge of sedimentary strata which increases gradually to a maximum recorded thickness of 514 m. Geologists in Saskatchewan have generally recognized this sequence as the Deadwood Formation and considered it to be Cambrian in age, although van Hees (1964) suggested the presence of several formations below the Deadwood, and Ross (1957) recovered Lower Ordovician fossils from the Deadwood in northeastern Montana.

Lefever et al. (1987) showed that the Deadwood Formation is over 250 m thick where it is most fully preserved in the central part of the Williston Basin in North Dakota. They subdivided it into six units, A through F in ascending stratigraphic order, and reported that Units A and B are Late Cambrian (Dresbachian through Trempealeauan) and Units C through F are Early Ordovician (Tremadocian through Arenigian). Their isopach maps show that it is mostly Units A and B, 100 m at their thickest development, which extend into Saskatchewan, with perhaps 50 m of Unit C present in the extreme southeast. Units D through F are restricted to the central part of the Williston Basin and are therefore entirely absent in Saskatchewan.

The above implies that the Deadwood Formation in eastern Saskatchewan is essentially Late Cambrian, with possibly a small area of Early Ordovician (Tremadocian) in the southeast. Units C through E extend westward into Montana, consistent with finds there of Lower Ordovician fossils by Ross (1957).

In the western part of southern Saskatchewan, Fyson (1961) called the entire sequence Deadwood Formation. He proposed three subdivisions: 1) Lower Deadwood Unit, 2) Middle Deadwood Unit, and 3) Upper Deadwood and Winnipeg Unit. He claimed the Winnipeg, which was poorly developed in the eastern part of his area, as a facies of the Deadwood and postulated the Cambro-Ordovician boundary to lie near the top of his Middle Deadwood Unit.

Van Hees (1964) went much further. He correlated the lower part of the sequence in western Saskatchewan with formations of Middle Cambrian age lying below the Deadwood Formation in Alberta. These are, in ascending stratigraphic order, the Cathedral, Stephen and Eldon Formations. He recognized also the Pika Member, a carbonate development at the top of the Eldon. Preliminary work being done by the author for the new Geological Atlas of the Western Canada Sedimentary Basin seems to substantiate some of these correlations. Van Hees's maps show these strata to extend eastwards from the Alberta border for some 275 km at the latitude of Lloydminster and for some 150 km into the southwestern corner of Saskatchewan where they attain a thickness of approximately 170 m. The rocks reach a thickness of nearly 250 m 100 km south of Lloydminster.

Van Hees recognized the upper part of the sequence as Deadwood Formation, assigning it a Late Cambrian – Early Ordovician age (Dresbachian through Tremadocian), and the uppermost strata to the east as Winnipeg Formation. His maps show the Deadwood extending almost to the Manitoba border, thickening in the west to some 300 m in the south-central part of the province and to approximately 340 m in an area 50 km north of Lloydminster. He has attempted to separate the Cambrian and Ordovician portions of the formation using the "m" marker of Fuller and Porter (1962). This separation implies the presence of some 200 m of Cambrian Deadwood and about 100 m of Ordovician Deadwood. In comparison, Lefever's figures are 100 m of Cambrian and 150 m of Ordovician in the Deadwood of North Dakota. It is instructive to compare the 300 m of Van Hees's Deadwood and the 250 m of Lefever's Deadwood with the much thicker 514 m of "Deadwood" presently ascribed to western Saskatchewan.

Conclusions

1) The lowermost Phanerozoic strata in western Saskatchewan are probably Middle Cambrian and correlate with the Cathedral, Stephen and Eldon Formations of southern Alberta.
2) The overlying strata in western Saskatchewan belong to the Deadwood Formation and are Late Cambrian to Early Ordovician (Dresbachian-Tremadocian).
3) In southeastern Saskatchewan, the Deadwood Formation rests directly on Precambrian basement and comprises strata of Dresbachian through Tremadocian age. It is not known if the Tremadocian strata are laterally continuous with their western counterparts across southern Saskatchewan.
4) In eastern Saskatchewan, only the Cambrian portion of the Deadwood is preserved, resting directly on Precambrian.
5) The Winnipeg Formation is present from the Manitoba border to within 100 km of the Alberta border. It overlies the Deadwood Formation in central southern Saskatchewan and rests directly on Precambrian in the extreme east. It is believed to be Middle Ordovician in age, possibly Caradocian.

References

Anderson, D. (1988): Progradational sequences in Lower Ordovician portion of Deadwood Formation, Williston Basin (abstract); Am. Assoc. Petrol. Geol., Rocky Mtn. Sect. Meet., Bismarck, N.D.

Carlson, C.G. (1960): Stratigraphy of the Winnipeg and Deadwood Formations in North Dakota; N. Dak. Geol. Surv., Bull. 35, 149p.

Carlson, C.G. and Anderson, S.B. (1965): Sedimentary and tectonic history of North Dakota part of the Williston Basin; Am. Assoc. Petrol. Geol. Bull., v49, p1833-1846.

Darton, N.H. (1901): Preliminary description of the geology and water resources of the southern half of the Black Hills and adjoining regions in South Dakota and Wyoming; U.S. Geol. Surv., 21st Annu. Rep., Pt.4, p502-508.

Dowling, D.B. (1900): Report on the geology of the west shore and islands of Lake Winnipeg; Geol. Surv. Can., Annu. Rep. F, 100p.

Fuller, J.G. and Porter, J.W. (1962): Cambrian, Ordovician and Silurian formations of the northern Great Plains, and their regional connections; Alberta Soc. Petrol. Geol. J., v10, no8, p455-485.

Fyson, W.K. (1961): Deadwood and Winnipeg stratigraphy in southwestern Saskatchewan; Sask. Miner. Resour., Rep. 64, 37p.

Lefever, R.D., Thompson, S.C. and Anderson, D.B. (1987): Earliest Paleozoic history of the Williston Basin in North Dakota; *in* Fifth International Williston Basin Symposium; Sask. Geol. Soc./N. Dak. Geol. Soc., Spec. Publ. 9, p22-36.

McCabe, H.R. (1978): Reservoir potential of the Deadwood and Winnipeg Formations in southwest Manitoba; Manit. Dep. Mines, Geol. Pap. 78-3, 54p.

Paterson, D.F. (1971): The stratigraphy of the Winnipeg Formation (Ordovician) of Saskatchewan; Sask. Miner. Resour., Rep. 140, 57p.

Ross, R.J. (1957): Ordovician fossils from wells in the Williston Basin, eastern Montana; U.S. Geol. Surv., Bull. 1021, Pt.M, p439-510.

Van Hees, M. (1964): Cambrian; *in* McCrossan, R.G. and Glaister, R.P.(eds.), Geological History of Western Canada; Alberta Soc. Petrol. Geol., Calgary, Chap. 3, Pt.1, p20-28.

Vigrass, L.W. (1971): Depositional framework of the Winnipeg Formation in Manitoba and eastern Saskatchewan; Geol. Assoc. Can., Spec. Pap. 9, p225-234.

Aggregate Exploration Program at the Saskatchewan Research Council

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Simpson, M.A. (1988): Aggregate exploration program at the Saskatchewan Research Council; *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4.

Seventy-five percent of all aggregate production in Saskatchewan is used in the construction and maintenance of grid roads and highways. The relatively low monetary value of this material makes haul cost a key factor in the economics of many deposits. In order to make optimum use of sand and gravel resources it is imperative that comprehensive information be available concerning location, reserves and quality of aggregate deposits.

In Saskatchewan, Rural Municipalities (RM) are responsible for the maintenance and construction of an extensive rural grid road system. Each year over 4 million tonnes of sand and gravel are applied to the grid road network. Many RMs are in dire need of new aggregate supplies. Still others are hauling from pits far from the eventual point of use. In order to assist RMs in the search for new sources of aggregate, the Saskatchewan Research Council (SRC) developed an "Aggregate Exploration Program". Partial funding for this program (50 percent) was made available through the Canada-Saskatchewan Mineral Development Agreement (MDA) in December of 1987 and the remaining 50 percent is paid by the specific RMs being studied.

The Aggregate Exploration Program involves field exploration work, consisting of auger drilling, back-hoe trenching, sampling and geophysical surveys, and an office compilation component consisting of airphoto interpretation and compilation of available sand and gravel information, including water well records, soils maps, surficial geology maps, and testhole information available from Saskatchewan Highways and Transportation.

The prospects identified by the airphoto investigation are further assessed by SRC through field investigations. A preliminary field inspection is made of all the prospects identified in the airphoto study. This work consists of an examination of existing terrain and exposures, digging of shallow holes, and preliminary geophysical work (EM-31). Those prospects warranting follow-up subsurface testing are thus identified and tested with back-hoe and/or auger-drill rig. Priorities for this more detailed testing are set in consultation with the council of the RM concerned.

The information derived from the exploration program is presented on maps with an accompanying report which is drafted, printed and distributed to the clients.

During the 1987/88 fiscal year, four RMs (Prairiedale, Oakdale, Lacadena and Leask), comprising an area of 4776 km^2, were investigated. A total of 165 aggregate prospects were identified and 251 testholes were drilled.

In the 1988/89 fiscal year, seven RMs (Harris, Perdue, Progress, Deer Forks, Rosedale, Biggar and Aberdeen), comprising an area of 6713 km^2, are under investigation. Airphoto identification of prospects and most of the fieldwork have been completed for these areas. A total of 248 aggregate prospects were identified via airphoto interpretation, 384 testholes were drilled and 101 aggregate samples analyzed. Final reports for all areas will be complete by March 1989.

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(1) Environment and Resources Branch, Saskatchewan Research Council, Saskatoon.

Abstracts of Recent Saskatchewan Energy and Mines Publications and Papers by Staff of the Saskatchewan Geological Survey

Fuzesy, A. (1987): Assessment work catalogue, Athabasca area, Saskatchewan; Saskatchewan Energy and Mines, Miscellaneous Report 87-6, 132p (supplement to Miscellaneous Report 84-8).

Gilboy, C.F. (1988): Geologic, logistic and economic controls on current shallow gas production in southwestern Saskatchewan (abstract); Am. Assoc. Petrol. Geol., Rocky Mtn. Sect. Meeting, Bismarck, Aug. 21-24.

Biogenic shallow gas is commercially produced from three Upper Cretaceous lithostratigraphic units in southwestern Saskatchewan: the second white-speckled shale, the Medicine Hat Sandstone, and the Milk River Formation. Major geologic characteristics of each of these units in the study area compare laterally with equivalent gas-producing strata in southeast Alberta (southeast Alberta Gas System) and north-central Montana (East Keith, Tiger Ridge - Bowes - Bull Hook, and Bowdoin fields).

Exploration for and, more particularly, development of shallow gas pools in southwestern Saskatchewan have greatly increased since 1982 (average number of gas wells per annum from 1960 to 1982 inclusive was 47, and from 1983 to 1987 inclusive was 460), despite a sharp decline in 1986. Logistic and economic factors influencing this pattern include current project-development methods and costs in this highly active gas play.

Guliov, P. (1988): Overview of industrial minerals in Saskatchewan (abstract of paper presented at 90th Annual General Meeting, Can. Inst. Min. Metall.); CIM Bull., v81, no911, p92.

Industrial minerals contribute substantially to the economy of Saskatchewan. In 1986, the total value of industrial minerals produced in the province was about $700 million, which is about 75 per cent of the value of mineral production excluding petroleum and natural gas and about one-third the value of all non-renewable resources. If lignite is classed as an "industrial mineral", as it is in Saskatchewan, then five commodities dominate the industry. These are, in decreasing order of significance, potash, lignite, sodium sulphate, sand and gravel, and salt. However, despite the contribution of industrial minerals to the mineral economy, the industry as a whole cannot be considered as well developed and probably only represents a small proportion of the latent potential. Their diversity in Saskatchewan presents numerous opportunities for research, development and industrialization.

Processing requirements of industrial minerals depend to a large degree on end use and the nature of the raw material and the technology of processing spans a broad spectrum of complexity. Some commodities such as silica smelter flux, granular aggregate and some ceramic clays require little or no processing. At the opposite extreme, complex processing may be necessary to alter the physical and chemical nature of minerals as in the case of upgrading of kaolin for the filler industry or the processing of silica sand for electronic and fibre optics application. These examples demonstrate that a global perspective of the industry, the related technology and a local and regional appreciation of available resources will lead to recognition of the diversity of opportunities and possibly to greater rewards for the innovative developer.

This paper presents a brief outline of the industrial mineral resources of Saskatchewan and attempts to highlight the more significant opportunities for development.

Harper, C.T., Thomas, D.J., Delaney, G.D. and Pearson, J.G. (1988): Controls on gold mineralization in the Reindeer Zone: an Early Proterozoic gold province, northern Saskatchewan, Canada (abstract); in Goode, A.D.T., Smyth, E.L., Birch, W.D. and Bosma, L.I. (eds.), Bicentennial Gold 88, Extended Abstracts, Poster Programme, Volume 1; Geological Society of Australia, Inc., Abstracts Series, no23, p143-145.

Between 1946 and 1984 gold exploration expenditures in Early Proterozoic greenstone belts in the Reindeer Zone of northern Saskatchewan amounted to approximately $29 million. An additional $28 million was spent from 1984 to 1986, and in excess of $35 million was slated for gold exploration in 1987. Up to 1984, exploration had yielded about 1.5 million ounces of gold in possible economic discoveries at an exploration cost of $19 per ounce. Comparable exploration costs in Archean greenstone belts of Quebec and Ontario are $23 per ounce and $15 per ounce ($43 per ounce prior to the Hemlo discovery) respectively. Since 1984 known gold reserves in northern Saskatchewan have continued to increase and many new exciting discoveries have been made.

The Reindeer Zone is a collage of Early Proterozoic accreted terranes, forming part of the Trans-Hudson Orogen (Fig. 1). The zone comprises: magmatic - migmatitic belts (Wathaman Batholith and Rottenstone Domain); greenstone belts (La Ronge (LRD), Flin Flon (FFD) and Glennie Lake (GLD) Domains and Hanson Lake Block); an inter-arc basin (Kisseynew Domain (KD)) and minor Archean crustal components (Hanson Lake Block and GLD in part). Gold occurs primarily in the greenstone belts of the LRD, GLD and FFD and less commonly in the KD.

The La Ronge Domain comprises a Central Metavolcanic Belt, flanked by metasedimentary gneisses of the Crew Lake and McLean Lake Belts to the northwest and southeast respectively. Gold occurrences are almost entirely restricted to the metavolcanic belt and are concentrated in four main areas; around Waddy, Tower, Star and Sulphide Lakes (Fig. 1). The gold occurrences are predominantly structurally-controlled quartz vein-type, with subordinate stratabound-type and several postulated epithermal-type. Geological and structural controls of the vein type include:

1) ductile to ductile-brittle shears developed in composite plutons (e.g., Star Lake 21 Zone) and surrounding supracrustals (e.g., Jolu);
2) fracture systems developed in and around quartz-rich granitic stocks (e.g., Komis); and
3) brittle fracture systems developed along regional structures such as the Byers Fault (e.g., Tower East).

Stratabound gold mineralization, commonly associated with felsic metavolcanics, is found in:

1) mixed oxide-silicate-sulphide facies iron formation (e.g., Twin Zone);
2) barren to base metal-enriched massive sulphides (e.g., Anglo Rouyn, Churchill Minerals);
3) carbonaceous, sulphidic metasediments (e.g., Sulphide Lake).

Base metal-silver-gold mineralization, which occurs in fracture controlled quartz-carbonate stringer zones in felsic metavolcanics (e.g., Earl Lake) or related metasediments (e.g., Jojay), is considered to represent modified (metamorphosed and tectonized) epithermal-type mineralization.

The Glennie Lake Domain is underlain by narrow, sinuous, generally southeast-trending greenstone belts separated by broader granitoid and migmatitic regions. In GLD structurally-controlled gold quartz veins occur in mafic to intermediate intrusions (e.g., Seabee) as well as supracrustals (e.g., Pigeon Lake). Rare stratiform mineralization is also present in volcaniclastics.

The few known gold occurrences in the Kisseynew Domain, an inter-arc sedimentary basin, are typically stratabound-type, being associated with sulphide-bearing amphibolite and calc-silicate rocks (e.g., Mari Lake).

Most of the historic gold production in the Reindeer Zone has come from the Flin Flon Domain, primarily as a by-product from the mining of base metal massive sulphide deposits (e.g., Flin Flon mine). The Flin Flon Domain possesses two distinctive volcanic assemblages; a predominantly oceanic tholeiitic basaltic assemblage in the eastern half (Flin Flon area) and an intermediate to felsic calc-alkaline island arc assemblage dominates the western half (Amisk Lake area). Gold occurrences in the two areas also differ. In the West Channel area of Amisk Lake, pre- to early syntectonic gold occurrences are characterized by quartz vein systems surrounded by broad carbonate, sericite and silica alteration envelopes developed in interlayered metavolcanics and metasediments (e.g., Monarch Mine) and subvolcanic felsic intrusives (e.g., Laurel Lake). Formation in a near surface, possibly epithermal environment is suggested in some of these deposits.

East of Amisk Lake gold occurrences are clearly structurally controlled quartz vein-types. A syntectonic group of quartz-sulphide-gold veins were emplaced in mafic metavolcanics along intermittently active fracture systems (e.g., Newcor Mine). Late- to post-tectonic fracture-controlled vein systems occur in and around late porphyritic intrusions and possess porphyry-style mineralization and alteration characteristics (e.g., Rio Mine). Syngenetic gold is present in the barren and base metal-rich massive sulphide deposits of the FFD.

Many of the features characterizing gold occurrences in the more publicized Archean greenstone belts can be shown to exist in the Reindeer Zone in northern Saskatchewan. Because the geological controls of mineralization are similar in both Early Proterozoic and Archean greenstone belts, the potential for further exploration successes in the Reindeer Zone is extremely high.

Kent, D.M., Haidl, F.M. and MacEachern, J.A. (1988): Mississippian oilfields in the northern Williston Basin; in Goolsby, S. and Longman, M. (eds.), Occurrence and Petrophysical Properties of Carbonate Reservoirs in the Rocky Mountain Region; Rocky Mountain Assoc. Geol., 1988 Symposium Volume.

The northern flank of the Williston Basin is a mature exploration play which has been actively producing commercial quantities of oil from Mississippian strata for about 37 years. Approximately 1.5 x 10^9 barrels of recoverable oil have been discovered within 114 oilfields in the Saskatchewan portion of the play.

The Mississippian strata consist of carbonates, evaporites and minor siliciclastics, representing a large-scale, shallowing-upward (progradational) sequence of basin, basin slope, outer shelf, shelf crestal, inner shelf and peritidal facies. These depositional facies are diachronous with marker-defined units (beds) which subdivide the Mississippian and subcrop at the sub-Mesozoic unconformity surface along northwest-southeast traces. Oilfields are preferentially located along the traces of six of the marker-defined units: Souris Valley, Tilston, Alida, Frobisher, Midale and Ratcliffe Beds.

Reservoir lithologies are highly variable and include:

1) sediment-gravity flow skeletal grainstones and packstones;
2) skeletal and coated-grain grainstone, packstone and wackestone shoal deposits;
3) dolomitized wackestones and lime mudstones; and
4) dolomitic quartz sandstones.

In addition, oilfields typically display at least one of the three main types of trapping conditions:

1) paleotopographic;

2) stratigraphic (subjacent to the unconformity); and

3) structural/stratigraphic (related to local drape structures).

Consequently, ten oilfields are employed in order to illustrate the variations in reservoir lithology, petrophysical characteristics and trapping mechanisms, namely: the Parkman Field (Souris Valley and Tilston production); the Alida East, Lost Horse Hill and Innes Fields (Frobisher-Alida production); the Benson, Glen Ewen and Weyburn Fields (Midale production); and the Hummingbird, Oungre and Flat Lake Fields (Ratcliffe production).

MacDougall, D.G. (1988): Metallogenic Map Series, Wollaston Lake, NTS Area 64L; Saskatchewan Energy and Mines, Report 254, 40p (accompanied by 1:250,000 scale map).

Parslow, G.R. and Gaskarth, J.W. (1988): Geochemistry of the Hamell Lake area, Saskatchewan; Saskatchewan Energy and Mines, Open File Report 87-4, 73p (plus 1 map).

Paterson, D.F. (1988): Metallic mineral occurrences in or under the Phanerozoic rocks of Saskatchewan; Geoscience Can., v15, no2, p103-105.

In Saskatchewan the Precambrian basement is exposed in the north and slopes to the south where it is covered by a progressively thicker sedimentary succession of Phanerozoic age. This succession reaches over 3000 m in thickness in the southeast, reflecting the Williston Basin structure that extends northward from North Dakota.

The mineral wealth of southern Saskatchewan includes oil, gas, coal, potash, sodium sulphate and bentonite. These are well known, but there are occurrences of metallic minerals which also warrant consideration. This paper summarizes those occurrences known in the sedimentary rocks or the igneous/metamorphic basement at shallow depths below them. Though not economically important today, some of these have been exploited in the past and others have potential for future development. Published references have been given where available; otherwise the original documents on which this paper is based can be consulted in the Mineral Assessment Section, Saskatchewan Energy and Mines, Regina.

Scott, B.P. (1988): Geology and geochemistry of silver occurrences near Dianne Lake (NTS 74N-10), Saskatchewan; Saskatchewan Energy and Mines, Open File Report 87-1, 46p (plus 3 maps).

The area surrounding Dianne Lake is underlain by rocks of Archean and/or Proterozoic age: biotite migmatite, hornblende gneiss, mylonitic felsic gneiss, diorite, granite and the unconformably overlying metasediments of the Thluicho Lake Group, comprising basal conglomerate, arkose and argillite. Easterly-trending diabase dykes are crosscutting to all units.

Three main fold sets are recognized. The first two of these are isoclinal, whereas the third and youngest, which is the most dominant, is characterized by upright, open folds whose axes plunge gently to the northeast.

Medium- to high-grade metamorphism is indicated by the occurrence of cordierite and sillimanite in biotite migmatite.

At Dianne Lake, low-grade silver and copper mineralization occur near the crest of a gently folded anticlinorium in biotite migmatite. High-grade native silver, associated with minor erythrite, occurs in vertical north-trending fractures.

Scott, B.P. (1988): Metallogenic Map Series, Lac la Ronge, NTS Area 73P/73I; Saskatchewan Energy and Mines, Report 255, 29p (accompanied by 1:250,000 scale map).

Sibbald, T.I.I. (1988): Geology and genesis of the Athabasca Basin uranium deposits; in Recognition of Uranium Provinces (Proceedings of a Technical Committee Meeting held September 1985); Internat. Atomic Energy Agency, Vienna, p61-105.

The Athabasca basin contains some 14% of the reasonably assured, low cost uranium reserves of the western world. It comprises a 1400 m thick, red bed succession, the Athabasca Group of Paleohelikian (ca. 1450 Ma) age and occupies an area of some 100 000 km^{2}. Fluviatile quartz sandstones and conglomerates give way upward to finer marine clastics and these in turn to stromatolitic and oolitic dolomite. Cross-cutting northwesterly trending diabase dykes are dated at between 938 and 1230 Ma. The Athabasca Group is underlain by a lateritic weathering profile in crystalline basement rocks belonging to two major subdivisions of the Saskatchewan Shield, the Cree Lake (Mobile) Zone and Western Craton. These are separated by a major shear zone, within a zone of low gravity which is locally intruded by Hudsonian (ca. 1750 Ma) uranium enriched 'granite'. The Cree Lake high-grade metamorphic zone comprises Lower Proterozoic shelf-type supracrustals (Wollaston Group) overlying predominantly granitoid basement, which was variably remobilized into gneiss domes and recumbent gneiss lobes during Hudsonian (*sensu lato*) orogenesis. In part, the supracrustals have become incorporated in the granitoid infrastructure. The Western Craton shows similar ages of rocks, but on a large scale has suffered plastic rather than ductile deformation, with the development of geologically complex zones of Hudsonian (*sensu lato*) reworking surrounding Archean granulite facies cratonic nuclei. Recognizable controls of Athabasca Basin uranium mineralization are: (a) the sub-Athabasca Group unconformity, (b) fracturing and faulting, and (c) graphite in basement rocks. The deposits exhibit, to varying degrees, complex mineralogy and geochemistry (U ± Ni, Co, As, Cu, Pb, Zn, Ag, Au, Pt group elements, Mo, V, Se, Mn and Fe). They are surrounded by extensive argillic alteration haloes in the Athabasca Group and more restricted haloes in the basement. Redox relationships are characteristic of most deposits. Dating of pitchblende and alteration minerals suggests epigenetic emplacement beginning 1350 Ma ago. Fluid inclusion studies indicate deposition from saline mineralizing fluids at temperatures between 150° and 225°C. The most acceptable model of deposit genesis, the diagenetichydrothermal model, involves interaction of hot, oxidized, metalliferous formational waters of the Athabasca Group with the underlying 'reduced' basement. Mineralization was episodic and likely triggered by tectonic events, possibly related to diabase dyke emplacement and/or uplift. The model requires neither local repeated enrichment by diverse processes throughout Earth history, nor the existence of a specialized, uranium enriched source.

Sibbald, T.I.I. (1988): Uranium-gold-platinum group metal mineralization in the Beaverlodge District of northern Saskatchewan (abstract); unpublished paper presented at Prospectors and Developers Association 1988 Annual Meeting.

Between 1953 and 1982, the Beaverlodge uranium district produced some 25 000 t of uranium metal from 17 main mines. The producing deposits, as well as numerous other radioactive showings in the area, are predominantly classical epigenetic vein-type pitchblende occurrences. Most are hosted by rocks of the metamorphic, Hudsonian (*sensu lato*) basement, although veins are also present in rift-deposited immature clastics and alkali basalts of the unconformably overlying Early to Middle Proterozoic (1700 - 1800 Ma) Martin Group. Mineralization is also known in the younger Middle Proterozoic (1450 - 1700 Ma) mature sandstones of the Athabasca Group.

Beck (1969) divided the epigenetic deposits into two groups, respectively showing simple and complex mineralogy. In the former, pitchblende is accompanied by brannerite, chalcopyrite, pyrite, galena and nolanite, and uranium by a simple suite of elements (Cu, Pb, Fe, V, S). In the latter, pitchblende and thucolite are accompanied by arsenides, sulphides, selenides and native metals, and uranium by a diverse group of elements (Cu, Ni, Co, As, Pb, Fe, V, Y, Se, Ag, Au, PGE). The association of uranium, gold and platinum group metals was first described in 1955, but only recently has exploration interest for the precious metals gained importance. Impetus has been provided by: 1) discovery of a potentially economic zone of gold-platinum group metal mineralization adjacent to the historically mined Coronation Hill uranium-gold deposit in the South Alligator River Uranium Field (SARUF) in the Northern Territory of Australia and, 2) recognition that Coronation Hill and other deposits in the SARUF show many similarities of mineralogy and geological setting to complex pitchblende veins in the Beaverlodge District. The regional geological analogy is further enhanced by the undoubted resemblance of the nearby world-class unconformity-type uranium deposits of the Alligator River Uranium Field to those within the Athabasca Basin of Saskatchewan. New exploration at Beaverlodge has identified, adjacent to historic uranium prospects, more extensive zones of gold and platinum group metal mineralization than previously recognized and has also resulted in new discoveries.

Cryptic gold and platinum group metal mineralization occurs within alteration zones commonly adjacent to uranium veins of complex mineralogy. These zones are characterized by: 1) hematization, silicification and talcification of host dolomitic marbles, diopsidic calc-silicates and quartzites, 2) extensive fracturing and, 3) development of vugs containing euhedral quartz, specular hematite and carbonates. There is a close spatial relationship to the sub-Martin Group and/or sub/Athabasca Group unconformities, and detailed field relationships and U/Pb (pitchblende) age data suggest mineralization after deposition of the Athabasca Group. Preliminary fluid inclusion studies from secondary euhedral quartz and carbonates from the altered/mineralized zones indicate fluids with temperatures in the range 150 - 200°C and high salinities. Similar fluids characterize the unconformity-type uranium mineralization of the Athabasca Basin.

The uranium-gold-platinum group metal deposits of the Beaverlodge District and SARUF represent a new type of low-temperature, hydrothermal precious metal mineralization. Their economic potential is as yet unknown, as is the exploration potential of the Early to Middle and Middle Proterozoic sandstone basins to which they appear related.

Slimmon, W.L., Sibbald, T.I.I. and Thomas, M.W. (1988): Compilation Bedrock Geology, Mudjatik, NTS Area 74B; Saskatchewan Energy and Mines, Report 244 (1:250,000 scale map with marginal notes).

Thomas, D.J. and Harper, C.T. (1988): A review of the Early Proterozoic "La Ronge Gold Belt", northern Saskatchewan; unpublished paper presented to Edmonton Geological Society, February 1988.

The region between La Ronge, Pelican Narrows and Southend in northern Saskatchewan has been loosely termed the "La Ronge Gold Belt". This region is underlain by the La Ronge and Glennie Lake Domains of the larger Reindeer Zone of the Trans-Hudson Orogen and comprises a collage of Early Proterozoic volcanosedimentary-plutonic terranes of primarily island arc affinity.

The majority of gold occurrences are found in the La Ronge Domain, particularly in a greenstone belt termed the Central Metavolcanic Belt (CMB). Rocks in the CMB display a range of well preserved subaqueous and subaerial primary volcanic features which suggest development in a volcanic arc environment. Major and trace element geochemistry supports such an interpretation. A spectrum of intrusive events are recognized ranging from "early", possibly in part synvolcanic, dykes and composite plutons, through "later" episodes involving large homogeneous felsic plutons and quartz-rich granite stocks. U-Pb zircon dating indicates major volcanism occurred about 1880 Ma ago and major plutonism between 1870 to 1830 Ma ago. Peak regional metamorphism affected the region prior to 1850 Ma ago. Bounding high strain zones that occur between the CMB and its flanking metasedimentary belts may represent zones along which southeastwards thrust movement occurred.

The Glennie Lake Domain (GLD), lying to the east of the La Ronge Domain, is composed of narrow, sinuous generally southeast-trending greenstone belts that are separated by broad granitoid and migmatitic regions. Recent work in the GLD suggest it may be a remnant of a separate but contemporaneous island arc with the adjacent La Ronge arc. Subsequent collision of the two arc systems is postulated.

There are more than 80 gold occurrences distributed throughout the La Ronge and Glennie Lake Domains with one mine presently in operation (Star Lake mine) and two at advanced underground exploration stages (Jolu Property and Seabee deposit). The gold occurrences are predominantly structurally-controlled quartz vein-type, although subordinate stratabound-type and several postulated epithermal-type are also present in these domains. Many of the features characterizing gold mineralization in the better publicized Archean greenstone belts can be shown to exist in the La Ronge Gold Belt.

The following abstract is from a paper in press. The work was partly funded by the Canada - Saskatchewan Subsidiary Agreement on Mineral Development 1984-89:

Delaney, G.D., Carr, S. and Parrish, R.R. (in press): Two U-Pb zircon ages from eastern Glennie Lake Domain, Trans-Hudson Orogen, Saskatchewan; in Radiogenic Age and Isotopic Studies, Report 2; Geol. Surv. Can., Pap. 88-2.

Within the eastern Glennie Lake Domain of the Trans-Hudson Orogen of Saskatchewan, the Wood Lake batholith intrudes metavolcanic and meta-arkosic rocks of the Pine Lake and Ourom Lake sequences.

The climax of deformation and metamorphism in the area postdates all of these units, but predates 1836 ± 7 Ma.

Single detrital zircon grains from the Ourom Lake meta-arkose are 1850 to 1863 Ma old, as demonstrated by nearly concordant analyses on single abraded grains. From zircon geochronology, the Wood Lake batholith is constrained to be 1850 + 1/ − 2 Ma old.

The synvolcanic arkosic rocks are thus 1850 Ma old, and together with metavolcanic rocks represent a younger cycle of volcanism and molasse-type sedimentation than previously recognized. Deformation and metamorphism of the region followed closely at about 1840 Ma.

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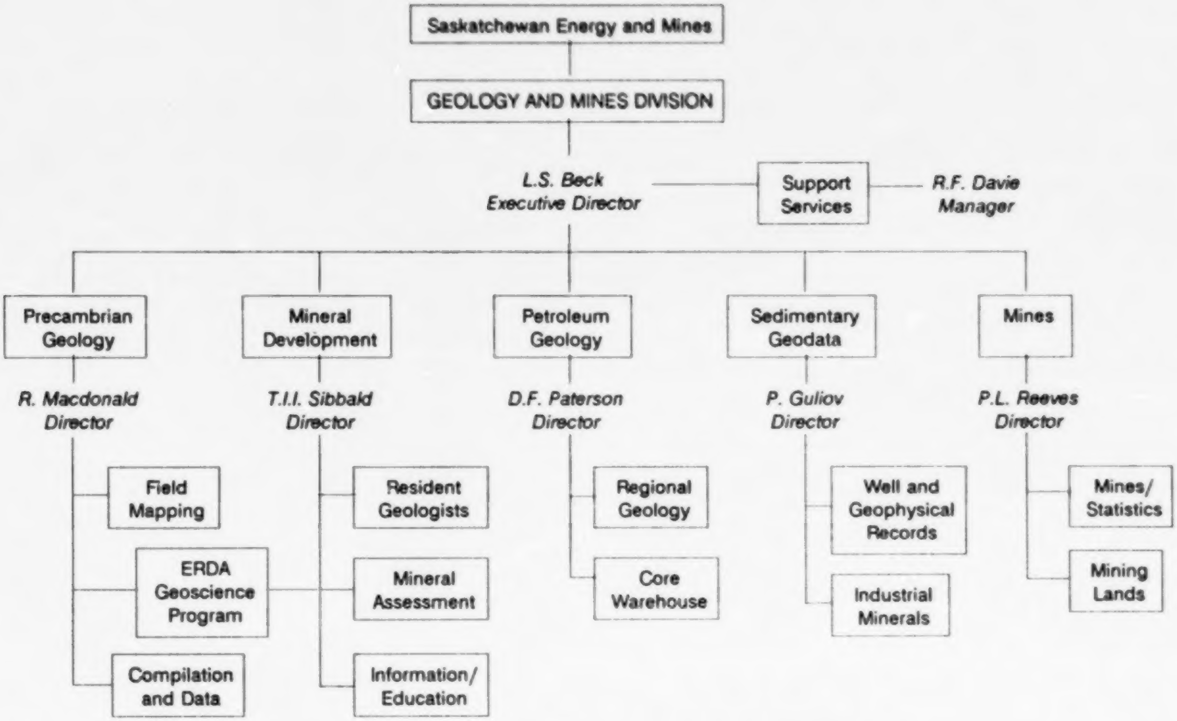
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[1] position contracted under Canada – Saskatchewan MDA 1984 – 89
[2] also serving Mineral Development Branch
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